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Opportune Landing Site Program

In Situ California Bearing Ratio Database

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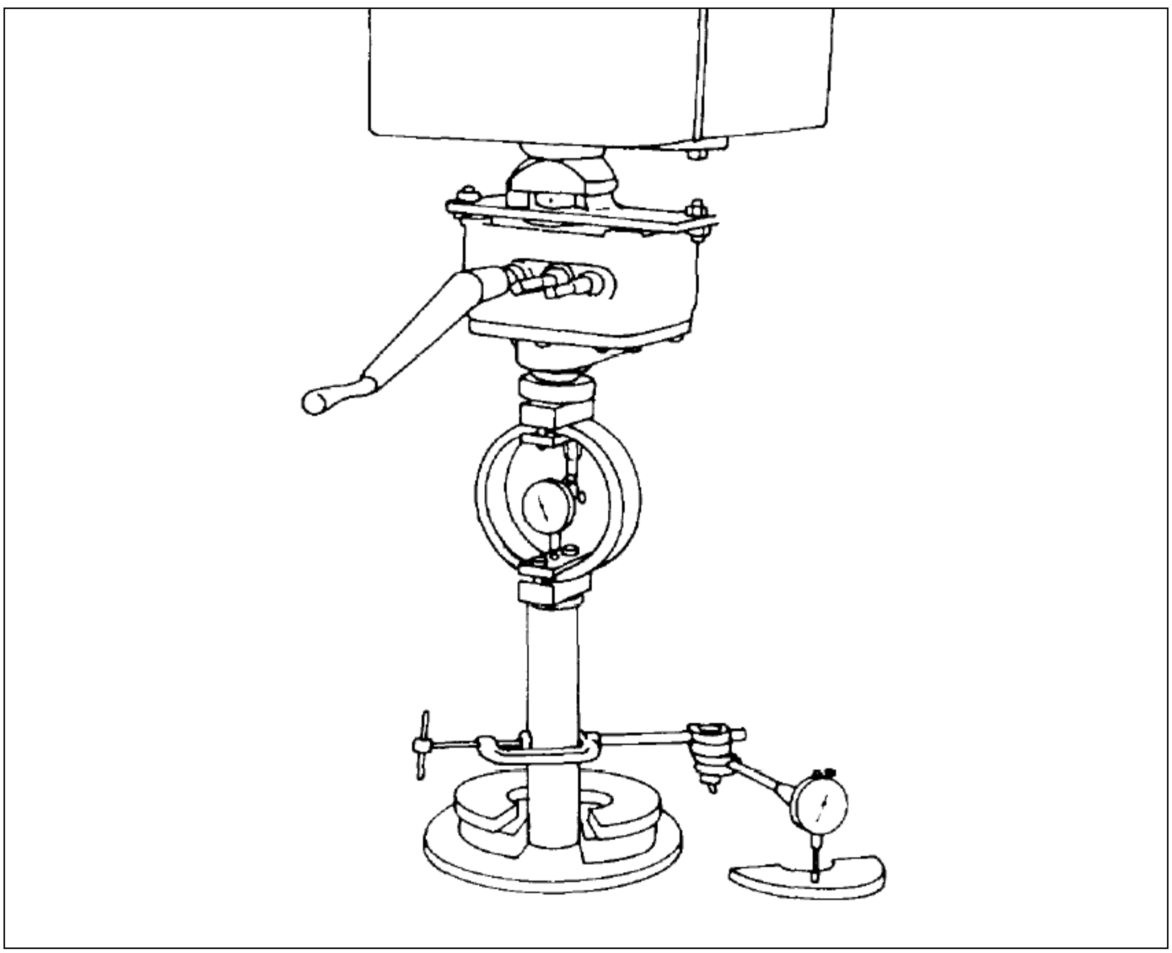

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Abstract: A global database of in situ soil test measurements and associated attributes was compiled for use in developing California bearing ratio (CBR) prediction models. From a variety of potential data sources, a collection of U.S. Army and Air Force airfield pavement research and evaluation reports was selected for inclusion. The schema includes data fields for common geotechnical parameters related to airfield pavement strength and geomorphological features associated with soil formation. More than 4,500 records from 46 test sites, representing 10 countries and 4 continents, were gathered and more than 1,500 of these contain field CBR test values. The database includes a wide variety of Unified Soil Classification System (USCS) soil types from a diversity of natural environments. The distribution of the numeric parameters in the database fall within the range of published distributions for natural soils reported in the literature.

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Preface

This report is a deliverable product in support of Customer Order No. GWRVA00472412, “Opportune Landing System,” conducted in collaboration with Boeing, the Air Force Research Laboratory (AFRL), and Syngenics Corporation. Dr. Charles C. Ryerson, Terrestrial and Cryospheric Sciences Branch, Cold Regions Research and Engineering Laboratory (CRREL), U.S. Army Engineer Research and Development Center (ERDC), Hanover, NH, was the Program Manager at ERDC-CRREL, and James McDowell, Air Vehicles Directorate, Air Force Research Laboratory, Wright-Patterson Air Force Base, was overall Program Manager.

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This report was prepared by Peter M. Seman and Dr. Sally A. Shoop, Research Civil Engineers, Force Projection and Sustainment Branch (FPSB), ERDC-CRREL, Hanover, NH, under the general supervision of Dr. Edel R. Cortez, Acting Chief, FPSB; Dr. Justin B. Berman, Chief, Research and Engineering Division; and Dr. Robert E. Davis, Director, CRREL. The authors acknowledge Deborah Diemand, James L. Cole-Henry, and Lynette A. Barna of ERDC-CRREL for their diligent and careful data entry work. Dr. Raymond S. Rollings and Lawrence W. Gatto, ERDC-CRREL retired, are also acknowledged for their helpful discussions regarding soil testing and geomorphological features. The authors thank Dr. Charles C. Ryerson and Deborah Diemand for their prompt and thoughtful reviews of this report.

COL Richard B. Jenkins was Commander and Executive Director of ERDC. Dr. James R. Houston was Director.

Unit Conversion Factors

Multiply	By	To Obtain
cubic feet	0.02831685	cubic meters
degrees (angle)	0.01745329	radians
feet	0.3048	meters
foot-pounds force	1.355818	joules
inches	0.0254	meters
pounds (force)	4.448222	newtons
pounds (force) per square inch	6.894757	kilopascals
pounds (mass)	0.45359237	kilograms
pounds (mass) per cubic foot	16.01846	kilograms per cubic meter
square inches	6.4516 E-04	square meters

Notation

#4 Avg	Average percent passing the number 4 sieve (4.75 mm)
#4 M	Maximum percent passing the number 4 sieve (4.75 mm)
#4 m	Minimum percent passing the number 4 sieve (4.75 mm)
#40 Avg	Average percent passing the number 40 sieve (425 μm)
#40 M	Maximum percent passing the number 40 sieve (425 μm)
#40 m	Minimum percent passing the number 40 sieve (425 μm)
#200 Avg	Average percent passing the number 200 sieve (75 μm)
#200 M	Maximum percent passing the number 200 sieve (75 μm)
#200 m	Minimum percent passing the number 200 sieve (75 μm)
0.005 Avg	Average percent finer than the 0.005 mm grain size
0.005 M	Maximum percent finer than the 0.005 mm grain size
0.005 m	Minimum percent finer than the 0.005 mm grain size
0.001 Avg	Average percent finer than the 0.001 mm grain size
0.001 M	Maximum percent finer than the 0.001 mm grain size
0.001 m	Minimum percent finer than the 0.001 mm grain size
3/4 Avg	Average percent passing the 3/4 inch sieve (19 mm)
3/4 M	Maximum percent passing the 3/4 inch sieve (19 mm)
3/4 m	Minimum percent passing the 3/4 inch sieve (19 mm)
CBR	California bearing ratio
CI	Cone index (trafficability)
DCP	Dynamic cone penetrometer
LL	Liquid limit
MC	Moisture content (gravimetric basis)
MDD	Maximum dry density
OMC	Optimum moisture content
PI	Plasticity index
PL	Plastic limit
SpGr	Specific gravity

1 Introduction

Because of the diverse, demanding, and time-sensitive nature of military operations, decision support systems—such as those being developed under the Opportune Landing Site (OLS) program— must be based on models that are applicable to the broadest possible range of locations and conditions likely to be encountered. To fulfill this objective, special consideration and attention were taken in compiling a unique database used for subsequent development of soil strength prediction methods with machine learning techniques (Semen 2006).

Objectives

From the beginning, it was apparent that the dataset would need to meet several unique requirements to be suitable for generating useful relationships among California bearing ratio (CBR) and other fundamental material properties for soils of interest to the OLS program. The constraints that guided the search for data included the following goals and motivations:

- Attempt to incorporate as many of the 26 Unified Soil Classification System (USCS) soil types into the database as possible. Because they are based on separating different regimes of engineering behavior in soil, a diversity of USCS classes should expose machine learning methods to all the mechanisms that drive soil strength.
- Ensure that the database is representative of the relative prevalence of the USCS soil types worldwide. In effect, the data should reflect how likely we are to encounter each of the different soil types in practice and encompass the larger variety that can be present in some of the more common soil types.
- Focus specifically on geotechnical parameters, especially those typically used to characterize engineering behavior in the pavement design and engineering community.
- Concentrate on records that contain actual California bearing ratio measurements, not other soil strength indices or parameters that can only be correlated to CBR.
- Make sure that the data encompass the range of conditions that we would expect to find in naturally deposited soils, which the OLS program seeks to characterize. Typical laboratory testing programs

concentrate on determining whether materials meet construction acceptance criteria. In this respect, care must be taken to ensure that results like these do not skew the database towards materials with superior engineering properties. For example, laboratory tests limited to high quality material for airfields and pavement applications could reflect higher densities, lower fines contents, and lower natural moisture contents.

- Incorporate as much geographic, geologic, environmental, and depositional diversity as possible. In this manner, there is some attempt at trying to reflect the wide variety of unique conditions under which natural soils can form.
- Bring together a consistent and well-documented dataset. The use of standardized test methods is critical for high confidence. Ensuring that individual data records are tied to their original sources can be useful in many respects: any peculiar soils could be isolated and dealt with separately if necessary, further information may be collected from documented sources to support future efforts, and inferences due to test locations or seasonal variation might be possible.

These principles formed the basis for evaluating potential sources of data for the OLS soil strength prediction study and the design of the database.

2 Literature Review

As part of a thorough survey, many different sources of data were considered as possible candidates for compiling the OLS CBR Database. These include U.S. Army Corps of Engineers (USACE) technical reports containing detailed geotechnical test results, soil mapping and soil survey efforts from the soil science and agricultural communities, airfield pavement evaluation reports generated by the U.S. Air Force (USAF) and USACE to monitor and assess these facilities, collaboration with parallel research efforts within the Corps of Engineers, and finally some emerging online and commercial geotechnical databases. Some of these sources proved to be incompatible with the constraints and objectives outlined in the previous section. In some cases, however, the sources that could not be utilized for the OLS CBR Database did prove useful in other ways. For example, a few of the resources were good models in developing a schema for this effort. And some of the efforts underway to develop geotechnical databases described below should provide much better opportunities for data mining and machine learning approaches in the future when they are completed.

Existing and Emerging Databases

Some of the soil mapping and soil survey work that was considered included global efforts at cataloging the world's soil resources. The United Nations Food and Agriculture Organization (FAO) produced a world soils map in the 1970s (FAO-UNESCO 1974). An effort is underway to update this map into an electronic Soil and Terrain Database (SOTER) product at much finer scale than the original (ISRIC 2004). Unfortunately, since the focus for these maps was agricultural productivity of the soils, there was very little specific engineering data that could be gleaned from them. The gross scales of these mappings, ranging from 1:5 million for the earlier map down to 1:250,000 for the SOTER product, are inadequate for the OLS objectives. In addition, the system of taxonomy used to describe soils in these maps are qualitative, and our ability to correlate these directly with the USCS system is tenuous at best. Despite these shortcomings, the SOTER methodology for classifying landforms, lithology of soil parent material, depositional processes, and clay mineralogy (van Engelen and Wen 1995) were found to be very helpful, and they were adopted for use in the OLS CBR Database schema.

Parallel research efforts within the ERDC were also consulted for use in compiling the OLS CBR Database. The ERDC soil database, an extensive worldwide dataset of several hundred soils, developed for the Joint Rapid Airfield Construction (JRAC) program, was evaluated for use in this investigation (Berney and Wahl 2007). The goal of the JRAC effort is to enable a rapid assessment of a soil with a miniaturized field soil laboratory kit, so that critical construction parameters such as USCS soil type, compaction curves, and design CBR values can be estimated within one hour. Unfortunately, the data collected for this work focused on providing a general summary of soil parameters and not the individual training cases that machine learning algorithms require to map specific input–output patterns.

Other current research at the ERDC is focused on soil strength from a ground vehicle mobility perspective that concentrates on the cone index (CI), a soil strength index test based on the static penetration of a 30° cone (ASAE 2004) that overlaps the lower end of the CBR range (Willoughby 1981). The Fast All-season Soil STrength (FASST) model, developed to predict the state of the ground in the theater of operations, includes the ability to forecast this soil strength index based on soil type and changing weather conditions (Frankenstein and Koenig 2004). However, the basis for the soil strength calculations is a model that relies only on a single exponential correlation between CI and moisture content for each USCS soil class (Sullivan et al. 1997). A related task under the OLS program to collect a database of CI related measurements is also underway (Diemand et al., in progress). Because these vehicle mobility database efforts do not focus on tests containing California bearing ratio measurements, they were not directly useful for building the OLS CBR Database.

Another body of soil data considered for the OLS CBR Database included some existing and emerging electronic geotechnical databases. A commercial off-the-shelf relational database containing six thousand distinct soils called SoilVision® was evaluated (SoilVision 2005). Even though the database is well organized and has fields for many of the engineering parameters we wanted to incorporate in the OLS CBR Database, the existing dataset included in this package concentrated mostly on hydraulic properties of soils and had little CBR information. Another existing soil database maintained by the U.S. Department of Agriculture's Natural Resources Conservation Service (formerly the Soil Conservation Service) contains some textural, plasticity, grain-size

uniformity, density, and moisture content test data, but it is focused on agricultural use and generally lacks strength data that are applicable to the current analysis (Soil Survey Staff 2006). Efforts are underway by the National Geospatial Intelligence Agency to build a global soils database (Dyke et al. 2003) by digitizing unpublished U.S. Department of Agriculture 1:1 million soil maps, but as with the SOTER mapping initiative, the scale and focus are not immediately useful for the OLS task. Another more relevant effort is underway by the USAF, called GeoBase, which aims to collect and archive data related to their air bases worldwide (Vansteenburg 2004). Included in this database will be information on pavement and soil data gathered in conjunction with construction projects, condition assessments, and airfield pavement evaluation report generation. While current activities do not collect CBR information directly, this dataset may prove useful to subsequent data mining efforts when it becomes available. Incorporation of historical test data into this framework would also be valuable, especially for the OLS program.

A final resource that may allow greater accessibility to geotechnical data in the future is Geotechnical Markup Language, an open source hypertext markup language scheme for soil data with an engineering focus (Toll 2005). If this initiative catches on, then future data miners could use this online international distributed repository to search for new relationships among material parameters for a wide variety of soils.

Sources Selected

Ultimately, the most valuable resources turned out to be two USACE technical reports and a selection of USAF/USACE airfield pavement evaluation reports. These contained a wealth of in situ field test and corresponding laboratory characterization data for a wide variety of soils from around the United States and locations around the world where the Department of Defense currently maintains bases or has in the past.

Two technical reports were selected for use in the OLS CBR Database. The first details an early study carried out by the Army Corps of Engineers immediately following World War II, which investigated moisture conditions under flexible airfield pavements (USACE 1955). Eleven field locations around the continental United States served as the test locations. The airfields chosen were located in arid, semiarid, and humid regions with minimal frost exposure. Previous attempts to measure moisture content with sensors proved unsuccessful with the technology available at

the time. Therefore, direct measurements of soil properties, including soil moisture sampling and numerous field CBR tests, were made in soil pits and boreholes dug within the pavement sections and adjacent non-paved areas. The availability of these field readings, coupled with thorough laboratory characterization tests performed on the same materials, made the report a particularly valuable repository of data relevant to the current investigation. A second technical report, involving a recent round of full-scale tests to help certify the C-17 airframe for semi-prepared runway operations (SPRO), was also used (Tingle 1998). This report contains detailed field test data from six semi-prepared runway locations mainly in the southwest United States.

The final resource used in the database included a selection of airfield pavement evaluation reports. These documents are produced for Army, Air Force, and Navy facilities on a regular basis to monitor pavement conditions over time, certify them for operational use by different aircraft, and help in planning ongoing maintenance and new construction projects. These reports contain extensive field and lab test results used in this process that tend to be very consistent because they are based on well-documented standard test methods that have changed very little over time (U.S. Army, Air Force, and Navy 1987). However, because of the shift in philosophy towards non-destructive assessment techniques in the 1990s, earlier evaluations that relied on excavation of subsurface test pits below the pavement proved to be the most valuable source of direct measurements of important soil properties. Because the destructive tests involve significant time, expense, and disruption of operations, they are very rarely carried out today. This makes this historical dataset a unique asset, representing a considerable investment of resources that is unlikely to be duplicated; it should be carefully preserved.

Data Management Recommendations

Support and proponency should be sought so that efforts to scan all available airfield pavement evaluation reports into an electronic format can continue. While digitization of the reports into a document management system is a good first step, efforts to populate a geotechnical information system relational database (such as GeoBase) with the test data itself will ultimately prove most useful for future research and analyses.

Unfortunately, enterprise-wide caretaking of costly geotechnical test results in the military does not receive the priority or dedicated funding that it deserves in many cases. For example, a recent survey of Army Corps of Engineers Districts revealed that the archiving of soil boring logs and laboratory test data was at best poorly coordinated and in some cases “truly archaic” (EarthSoft 2004). The negligible cost of proper data stewardship must be weighed against the risks of losing test results or duplication of effort. “In one Army Corps District, tens of thousands of dollars were spent unnecessarily on drilling new boreholes within meters of previous drilling sites, simply because they didn’t know that the data existed” (Weaver and Madison 2004).

3 Compiling the Database

Data collection for the OLS CBR Database took place in two phases, each yielding approximately half of the records in the final dataset. The first phase focused on the two Army Corps of Engineer technical reports discussed above (USACE 1955, Tingle 1998). A second phase incorporated some of the available airfield pavement evaluation reports, as described below.

Prioritization of Sources

A considerable number of pavement evaluations are available, and they needed to be prioritized in terms of their value for the OLS CBR Database. In a hard-copy archive at ERDC-CRREL containing evaluations from the 1940s to the present, an estimated 871 reports were cataloged (Fig. 1). A second archive, kept by the Air Force Civil Engineering Support Agency, was surveyed during March 2005 (AFCESA 2005). This repository contained an undetermined number of evaluations from the 1960s onward, which were scanned into Adobe® Portable Document Format (PDF).

Working with the AFCESA electronic archive because of its ease of access and sharing, we identified reports containing test pits with field CBR measurements. A total of 937 pits from 161 airfield pavement evaluation reports were cataloged. For each report the number of pits containing CBR information and an approximate ordinal ranking of the USCS soil types present were recorded. Using this information, a prioritization scoring system was created for these reports to estimate the amount of useful data in each and to guide the data entry process. The prioritization consisted of a composite score assigned to each report, incorporating the number of CBR pits in a report, the relative prevalence of each soil type for that site, and the degree of need for that soil type in the database after the first phase of data collection. In this way the evaluation reports were ordered so that the highest ranked might provide the most data for the soil classes that were still lacking in the database.

Because of the unique complexity of organic soil behavior and the lack of these soils in constructed airfields (because of their undesirable engineering properties), organic soils were not deliberately targeted for collection.

Ultimately, 32 airfield pavement evaluation reports representing 17 locations within the continental United States (CONUS) and 12 bases outside the continental U.S. (OCONUS) were entered into the OLS CBR Database (AFCEC 1974a, 1974b, 1975a, 1975b, 1976, 1977, 1978; AFESC 1979, 1980a, 1980b, 1980c, 1980d, 1980e, 1980f, 1981a, 1981b, 1981c, 1981d, 1981e, 1982a, 1982b, 1982c, 1982d, 1983, 1984a, 1984b, 1985a, 1985b, 1987a, 1987b, 1988; USACE 1969). These included 378 soil pits, approximately 40% of those identified in the 161 reports cataloged.

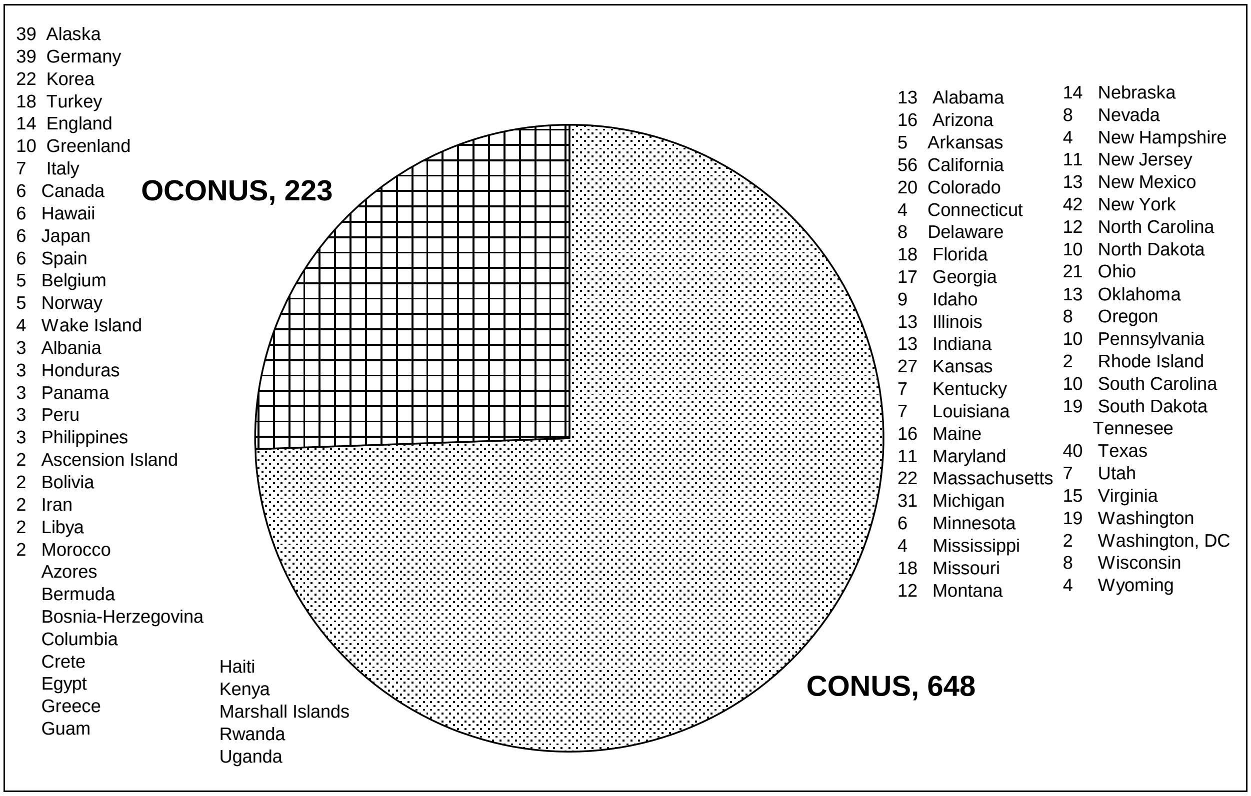

Figure 1. Number of airfield pavement evaluation reports in the CRREL archive by location.

Selection of Data Fields

From the technical and airfield pavement evaluation reports, the information detailed in Table 1 was compiled. A total of 62 fields were chosen to store information about data identification, reference source documentation, sample site description, soil classification, physical property data, strength index testing (both laboratory and field), particle sizes and shapes, and remarks. The definition and contents for each of these fields is described in further detail in Appendix A.

Table 1. Fields* in the Opportune Landing Site California Bearing Ratio Database.

OLS Data Point #	Moisture Content as Tested (weight %)
JRAC Soil #	Moisture Content as Tested (volumetric %)
Test or Sample Date	Trafficability Cone Index (CI)
Report #	Remolding Index
Report Date	DCP Index (dynamic cone penetrometer)
Report Title	Field CBR
Country Code (ISO-3166)†	Field Dry Density
Location	Field Wet Density
Test Station	¾ inch Sieve, Maximum Percent Passing
Layer	¾ inch Sieve, Minimum Percent Passing
Landform	⅜ inch Sieve, Maximum Percent Passing
Lithology of Parent Material	⅜ inch Sieve, Minimum Percent Passing
Deposition Type	#4 Sieve, Maximum Percent Passing
Depth to Water Table	#4 Sieve, Minimum Percent Passing
Soil Type, USCS	#10 Sieve, Maximum Percent Passing
Alternate Soil Type	#10 Sieve, Minimum Percent Passing
Alternate Soil System	#40 Sieve, Maximum Percent Passing
Soil Description	#40 Sieve, Minimum Percent Passing
Clay Mineralogy	#100 Sieve, Maximum Percent Passing
Specific Gravity	#100 Sieve, Minimum Percent Passing
Sample Depth Below Grade	#200 Sieve, Maximum Percent Passing
Plastic or Non-Plastic	#200 Sieve, Minimum Percent Passing
LL (liquid limit)	0.005 mm, Maximum Percent Passing
PL (plastic limit)	0.005 mm, Minimum Percent Passing
PI (plasticity index)	0.001 mm, Maximum Percent Passing
Compactive Effort	0.001 mm, Minimum Percent Passing
Molding Moisture Content	Roundness, Gravel
Dry Density (laboratory)	Roundness, Sand
Optimum Moisture Content and Max. Density	Sphericity, Gravel
Unsoaked CBR (laboratory)	Sphericity, Sand
Soaked CBR (laboratory)	Remarks

* See Appendix A for a detailed description of each field.

† Two-letter standard code from the International Standards Organization (2005).

Features were chosen by consulting with a group of subject matter experts to determine a broad range of data types that may either have a quantitative relationship to soil strength or allow inferences to be made

about soil conditions. Even though many were not filled either at all or to a significant degree, this large number of fields was useful in providing a comprehensive scheme for all data types that might be encountered in any of the literature sources surveyed, flexibility for further data collection in the future, and crossover with other databases (such as the OLS cone index work) for possible merging at a later date.

The manner in which grain size data were presented in the airfield pavement evaluation reports necessitated two fields for each particle size. In many of these reports, similar soils were grouped into families represented by a band in the plot of grain size distribution. Maximum and minimum values were used to capture this range of particle sizes for each soil, with the intent that this would fully capture the available information and might be useful for probabilistic analyses incorporating parameter distributions.

Data Entry

The OLS CBR Database required considerable effort to assemble. The use of optical character recognition (OCR) software to capture the data from the documents was explored, but the table and graph formats in the reports did not lend themselves well to this technique. Ultimately, manual data entry was used, which proved to be slow; however, the deliberate approach did provide some benefits. This methodical approach yielded a consistent dataset, and close error checking provided a high degree of data integrity that allowed confidence during subsequent analysis work. Perhaps the availability of better OCR tools in the future may simplify and encourage further data collection efforts.

To avoid confusion as to which data fields contained measured values versus those subsequently derived from other measurements, numerical fields contain only the basic measured values reported in the source, and derived parameters are blank (in general). For example, wet density or volumetric moisture content can be calculated if both dry density and gravimetric moisture content are known. However, if all four of these parameters are included in one record, it is not clear which ones were originally reported or measured. One exception to this rule was Atterberg limits, because they are interrelated by definition.* For these, the third parameter was derived from the other two and included in the record.

* Plasticity index = liquid limit – plastic limit

For several data fields, some generalizations, inferences, or assumptions were made during the data entry process. Entries for the "landform," "lithology of parent material," "deposition type," "depth to water table," and "clay mineralogy" attributes were garnered from information in background discussions in the reports, which sometimes gave a very general impression of the geologic conditions over the entire site. Because these were typically broad, entries for a single site tend to be the same for all cases. Alternatively, some entries for landform were inferred from maps, satellite imagery, or photographs of the sites when these general site descriptions were not included.

For the "layer" data field, some cases were assigned values based on their location relative to adjacent layers. All samples at depths below layers explicitly identified as a subgrade were assumed to also be in the subgrade. In some cases where the soil type was consistent with an adjacent layer explicitly identified as base or subbase course, those records were assumed to also be from the same layer type.

For the "plastic or non-plastic" data field, soils for which numerical values were reported for the Atterberg limits with a plasticity index greater than zero were considered plastic. Only soils that were explicitly identified in the reports as non-plastic were entered as such. For all other records, the "plastic or non-plastic" field was left blank, indicating an absence of reported information.

For gradation (particle size) data, a range of standard sieve sizes were targeted for data entry. Several points were chosen from the continuous gradation curves, with a spacing that was considered sufficient to capture their general shape and at values that the original testing was likely performed. The majority of the data collection efforts focused only on the ¾ inch, #4, #40, #200 sieves and the 0.005 and 0.001 mm particle sizes from the hydrometer analyses of the fine soil fraction. Originally, a total of nine sizes (the six above plus the ⅜ inch, #10, and #100 sieves) were included in the database schema. However, as data entry proceeded, we concentrated only on six to save time but still provide adequate coverage of the full gradation curve.[*]

[*] A few records contain data for the ⅜ inch, #10, and #100 sieve sizes. Their absence in a record does not necessarily mean that data for these sizes are unavailable in the original report.

4 Summary of Data Distribution and Statistics

A total of 4,608 records of separate field test conditions were collected from all sources. Before proceeding with further analysis, 16* were set aside because they were either stabilized with cement (10 records) or had compaction energy of CE 26 (6 records) that differed from all other records, which were CE 55 (DoD 1964). Consequently, all dataset descriptions that follow are for the remaining 4,592 records.

Approximately one third of all records (1,580) contained information regarding the California bearing ratio. The remaining two thirds were collected because it was easier to record all the data from each report during the data entry process. Also, these records provided useful soil condition information for determining correlations among the non-CBR features and could be valuable in further data mining efforts not focused on CBR. For 47 records, non-numeric CBR data were recorded (e.g., "CBR ≥ 100") in order to retain full information. Also, these could be used for models involving classification or probability distribution. However, most of the records (1,533) containing CBR information had an integer value for the strength index.

Geographic Distribution of Records

The data collected for the Opportune Landing Site California Bearing Ratio Database came from 46 test sites, shown in Table 2. The number of records is listed for each site, both for the full dataset and for the 1,533-record subset of those containing the numerical CBR value. These sites include 34 from within the continental U.S., 7 located around the Pacific Ocean, and 5 from in or near Europe. The geographical distribution of these sites, shown in Figures 2, 3, and 4, represents a variety of locations around the world. They encompass a broad range of geologic and environmental conditions, such as arid deserts, humid tropics, glacial till, coral islands, alluvial plains, volcanic deposits, dry lakebeds, and frost-

* The records eliminated from further analysis were OLS data point numbers 1956 through 1965 (cement stabilized) from Holland Landing Zone and numbers 3027, 3053, 3090, 3117, 3118, and 3121 (CE 26) from Myrtle Beach Air Force Base. However, these records remain in the OLS CBR datafile on record.

active areas. Therefore, they should cover many of the different combinations of conditions and processes that lead to soil formation.

Table 2. Number of records in the OLS CBR Database and CBR-only subset by test location.

Airfield Name	Location	ICAO* Code	Total Records	CBR† Records
Alamo Landing Zone	Alamo, Nevada	--	12	12
Andersen Air Force Base	Yigo, Guam	PGUA	56	31
Bergstrom Air Force Base	Austin, Texas	KAUS	280	100
Bicycle Lake Army Airfield	Fort Irwin/Barstow, California	KBYS	13	13
Castle Air Force Base	Atwater, California	KMER	80	16
Clark Air Base	Angeles City, Philippines	RPMK	103	33
Clovis Air Force Base (currently Cannon Air Force Base)	Clovis, New Mexico	KCVS	231	45
Craig Air Force Base	Selma, Alabama	KSEM	105	65
Edwards Air Force Base (Rogers Dry Lakebed)	Edwards, California	KEDW	5	5
Eglin Air Force Base	Valparaiso, Florida	KVPS	92	23
Eielson Air Force Base	Fairbanks, Alaska	PAEI	71	21
George Air Force Base	Victorville, California	GAFB	190	46
Goodfellow Air Force Base	San Angelo, Texas	KGOF	189	85
Hancock Field Air National Guard Base	Syracuse, New York	KSYR	38	17
Hickam Air Force Base	Honolulu, Hawaii	PHNL	126	54
Holland Landing Zone	Fort Bragg, North Carolina	--	1	0
Holloman Air Force Base	Alamogordo, New Mexico	KHMN	163	39
Indian Springs Airfield (currently Creech Air Force Base)	Indian Springs, Nevada	KINS	61	19
Kadena Air Base	Okinawa, Japan	RODN	277	55
Keesler Air Force Base	Biloxi, Mississippi	KBIX	105	45
Kingsley Field Air National Guard Base	Klamath Falls, Oregon	KLMT	140	30
Kirtland Air Force Base	Albuquerque, New Mexico	KABQ	294	94
Loring Air Force Base	Limestone, Maine	KLIZ	67	33
Luke Air Force Base	Glendale, Arizona	KLUF	51	28
Marana Air Park	Marana, Arizona	KMZJ	122	33
Maxwell Air Force Base	Montgomery, Alabama	KMXF	78	12
McChord Air Force Base	Tacoma, Washington	KTCM	41	25
McGuire Air Force Base	Wrightstown, New Jersey	KWRI	117	29
Memphis Municipal Airport (currently Memphis International Airport)	Memphis, Tennessee	KMEM	147	71
Myrtle Beach Air Force Base	Myrtle Beach, South Carolina	KMYR	108	31

Airfield Name	Location	ICAO* Code	Total Records	CBR† Records
Nellis Air Force Base	Las Vegas, Nevada	KLSV	107	20
Quonset State Airport	North Kingstown, Rhode Island	KOQU	60	21
Royal Air Force Mildenhall	Suffolk, England	EGUN	57	16
Santa Fe Municipal Airport	Santa Fe, New Mexico	KSAF	286	74
Sidi Slimane Air Base	Sidi Slimane, Morocco	GMSL	77	29
Sondrestrom Air Base	Kangerlussuaq, Greenland	BGSF	44	28
South Plains Air Force Base (was renamed Reese Air Force Base)	Lubbock, Texas	KREE	84	32
Spangdahlem Air Base	Binsfeld, Germany	ETAD	20	10
Tyson Landing Zone	Yuma Proving Grounds, Arizona	--	15	15
Vicksburg Municipal Airport	Vicksburg, Mississippi	KVKS	108	66
Waterways Experiment Station, Asphalt Test Section	Vicksburg, Mississippi	--	96	25
Wake Island Airfield	Wake Island	PWAK	62	21
Westover Air Force Base	Chicopee, Massachusetts	KCEF	74	23
Wheeler Air Force Base	Wahiawa, Hawaii	PHHI	61	17
Wilde-Benton Landing Zone, Fort Bliss	Orogrande, New Mexico	--	11	11
Zaragoza Air Base	Zaragoza, Spain	LEZG	67	15

* International Civil Aviation Organization airport code, a unique four-letter alphanumeric designation for locating airports worldwide (ICAO 2007).

† Records with numeric CBR values only.

Figure 2. Geographic distribution of the continental United States (CONUS) test sites. (Image courtesy of Google Earth™ mapping service.)

Figure 3. Geographic distribution of the Pacific area test sites. (Image courtesy of Google Earth™ mapping service.)

Figure 4. Geographic distribution of the European area test sites. (Image courtesy of Google Earth™ mapping service.)

Distribution of Records by USCS Soil Type

A summary of the Unified Soil Classification System soil types contained in both the full database and the numerical CBR subset appears in Table 3. These give some indication of the variety of soils included in the entire dataset and in the CBR-only subset. To get some sense of how well the database represents global soils, a comparison was made to an existing estimate of worldwide prevalence of USCS soil types (Robinson and Rabalais 1993). Figure 5 shows the percentage distribution of each soil type relative to the total number of records in each dataset, while the associated values from Robinson and Rabalais are an estimated percentage based on overall land area. The chart shows that the distribution in the numerical CBR subset tracked the overall database quite closely. Some exceptions to this include a slight increase in the number of gravel soils (GW, GP, GM, GC) and a significant decline in low-plasticity clays (CL) and high-plasticity silts (MH) for the CBR records.

The differences in the database distribution and the worldwide estimate are more significant, but some similarities do exist. SM, CL, CH, and SC soils are the most common soils in the worldwide estimate, while SM and CL—followed by SC—are the most common in the CBR subset. The CL and CH soils are slightly under-represented in the database, and the global

dominance of SM soils over all others is not present. Also, the worldwide estimate contains no gravel soils (USCS classes beginning with a G), while these are quite common for the database. This reflects the fact that the data collection concentrated on airfield pavement structures, which are deliberately designed and constructed with granular base and subbase material. The number of ML and SP soils is greater in the database than would be expected from the worldwide estimate. The reasons for this are not entirely clear, but we speculate that these soil types may be most common on smooth, flat landforms where airfields are likely to be placed. Also, very few CL-ML soils are found in the database compared to the worldwide estimate, and, by design, organic soils (OL, OH, and Pt) were specifically not targeted in the data collection process. While it is unclear whether the database or the estimate by Robinson and Rabalais (1993) represents an accurate assessment of the worldwide distribution, the database clearly exhibits a good distribution of USCS soil types.

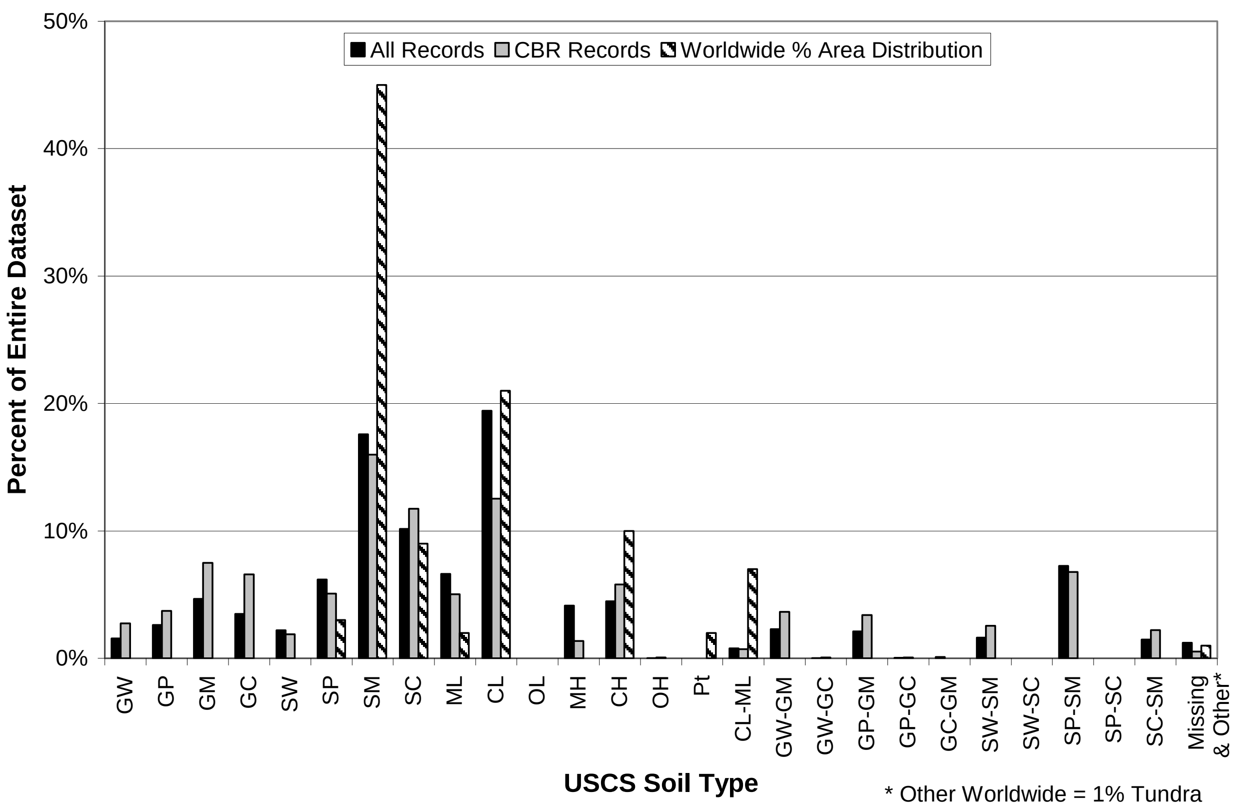

Figure 5. Distribution of records by USCS soil type compared to a worldwide estimate (Robinson and Rabalais 1993).

Table 3. Distribution of USCS soil types in the OLS CBR Database and subset.

USCS Soil Classification	Total Records	CBR* Records
GW	71	42
GP	120	57
GM	214	115
GC	160	101
SW	101	29
SP	284	78
SM	807	245
SC	466	180
ML	304	77
CL	892	192
OL	0	0
MH	190	21
CH	205	89
OH	1	1
Pt	0	0
CL-ML	36	11
GW-GM	105	56
GW-GC	1	1
GP-GM	97	52
GP-GC	2	1
GC-GM	5	0
SW-SM	75	39
SW-SC	0	0
SP-SM	333	104
SP-SC	0	0
SC-SM	67	34
Missing	56	8
TOTAL	*4592*	*1533*

* Records with numeric CBR values only.

Descriptive Statistical Summary

To provide a sense of the relative distribution of records for each of the data fields, statistical summaries for both the full database and the numeric CBR subset are provided in Table 4 and Table 5. These contain only the numerical fields from the database and include only those that held significant amounts of unique data (i.e. none that were empty or contained unvarying parameters that were common to all or most entries). A more detailed presentation of the distribution of these, additional numerical fields, and other categorical data fields is included in Appendix B for the full database.

The statistical summary presented in Table 4 clearly shows that a significant portion of entries for the 4,592 records in the database were incomplete to some degree. In fact for the entire 62 fields in the database (Table 1), the incompleteness factor[*] was a full 65% of all entries. However, as noted previously, the structure was set up more for flexibility than with the intention of filling all records completely. A total of 13 fields[†] were completely unused, and an additional 8[‡] contained data for less than 5% of all records. Another 12 fields[§] contained essentially descriptive or reference information that were generally not useful for prediction method analysis. Information for the fields containing landform, lithology of the soil parent material, method of soil deposition, and depth to water table were gleaned from the text of the pavement evaluation reports or inferred by their geographic location. As such, the subjective nature of these data resulted in a low degree of confidence, so it was not used in the data mining process.[**] Of the remaining 26 fields in the database that were not mostly empty, reference information, or subjectively assigned, the

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* The incompleteness factor is the percentage of attributes missing from the dataset for all records taken as a whole.

† The 13 completely empty fields were Alternate Soil System; Alternate Soil Type; Clay Mineralogy; Unsoaked CBR; Soaked CBR; Moisture Content as Tested (volumetric %); Trafficability Cone Index (CI); Remolding Index; DCP Index (dynamic cone penetrometer); Roundness, Gravel; Roundness, Sand; Sphericity, Gravel; and Sphericity, Sand.

‡ The eight fields with data for less than 5% of records were JRAC Soil #; Field Wet Density; ⅜ inch Sieve, Maximum Percent Passing; ⅜ inch Sieve, Minimum Percent Passing; #10 Sieve, Maximum Percent Passing; #10 Sieve, Minimum Percent Passing; #100 Sieve, Maximum Percent Passing; and #100 Sieve, Minimum Percent Passing.

§ The 12 descriptive/reference fields include OLS Data Point #; JRAC Soil #; Test or Sample Date; Report #; Report Date; Report Title; Country Code (ISO-3166); Location; Test Station; Soil Description; Optimum Moisture Content and Max. Density; and Remarks.

** Another problem exists with using these features for modeling. Although geomorphological factors influence the formation of different soil types, direct linkages are difficult to establish (Wysocki et al. 2000).

incompleteness factor improved slightly to an overall 59% missing data. The pavement layer, moisture content, USCS soil type, and depth below grade were the most complete features, ranging from 84% to 100% of the records. The fine particle sizes (0.005 and 0.001 mm) were the least complete features, only containing data in approximately 10% of the records.*

* However, this would be expected as these are typically measured only for fine-grained soils, such as silts and clays, where there is a significant portion of fine material present, and requires a hydrometer analysis in addition to a sieve analysis.

Table 4. Statistical summary of numeric features in the full database.

Feature* (units)	Valid Records	Quantiles					Mean	Standard Deviation	Coeff. of Var. (%)
		0%	25%	50%	75%	100%			
LL† (%)	1,999	14	23	30	44	85	34	14	41
PL† (%)	1,999	9	15	18	22	49	19	6	32
PI† (%)	1,998	1	6	13	21	53	15	10	69
SpGr	2,638	2.296	2.640	2.670	2.700	2.994	2.675	0.075	3
Depth** (in.)	4,592	0	11	20	34	90	23	16	70
OMC†† (%)	1,295	3.8	8.0	10.2	14.5	31.5	12.1	6.0	49
MDD†† (lb/ft^3)	1,343	89.0	112.5	124.5	131.5	151.0	122.1	12.7	10
MC (%)	4,020	0.5	5.8	10.8	17.1	85.3	12.8	8.8	69
DD (lb/ft^3)	1,686	64.5	104.3	116.2	128.7	168.7	116.4	16.2	14
3/4 M (%)	1,004	24	93	100	100	100	94	10	11
3/4 m (%)	1,004	24	71	90	99	100	83	17	21
#4 M (%)	1,817	12	68	96	100	100	83	22	26
#4 m (%)	1,817	10	53	86	99.5	100	76	26	34
#40 M (%)	1,004	4	33	60	91	100	61	30	49
#40 m (%)	1,004	4	20	35	76	99	46	32	68
#200 M (%)	1,838	0	14	32	54	100	38	29	76
#200 m (%)	1,834	0	6	24	50	100	32	30	93
0.005 M (%)	496	0	4	10	18	89	18	24	131
0.005 m (%)	496	0	0.25	2	8	75	10	18	178
0.001 M (%)	466	0	2	5	11	72	13	20	153
0.001 m (%)	466	0	0	0	5	57	7	14	207
CBR (%)	1,533	1	16	30	65	158	42.3	32.5	77

* Key to abbreviations and acronyms used for features can be found in Notation section.

† Atterberg limits for cohesive soils only.

** Depth below grade level including pavement thickness, if present.

†† Standard CE 55 compaction (DoD 1964).

Table 5. Statistical summary of numeric features in the CBR-only subset.

Feature* (units)	Valid Records	Quantiles					Mean	Standard Deviation	Coeff. of Var. (%)
		0%	25%	50%	75%	100%			
LL† (%)	726	14	22	28	40	85	32	13	42
PL† (%)	726	11	14	18	22	47	19	6	31
PI† (%)	725	1	5	11	17	53	13	10	76
SpGr	1,088	2.296	2.640	2.670	2.700	2.994	2.669	0.079	3
Depth** (in.)	1,533	0	4	12	17	72	13	11	83
OMC†† (%)	698	3.8	7.8	10.0	13.9	31.5	11.2	5.2	46
MDD†† (lb/ft³)	733	89.0	112.5	125.0	133.0	151.0	123.8	12.1	10
MC (%)	1,476	0.5	5.1	8.2	14.1	50.3	10.4	7.1	69
DD (lb/ft³)	1,380	64.5	104.2	116.0	128.9	168.7	116.5	16.2	14
3/4 M (%)	526	24	89	98	100	100	92.5	11	12
3/4 m (%)	526	24	70	83.5	98	100	80	18	23
#4 M (%)	849	12	54	81	100	100	77	24	31
#4 m (%)	849	10	44.5	74	98	100	69	27	39
#40 M (%)	526	4	25	50	87	100	55	30.5	55
#40 m (%)	526	4	15	26	68	99	40.5	31	76
#200 M (%)	863	0	10	22	44	100	32	28	87
#200 m (%)	861	0	5	14	38	100	26	28	109
0.005 M (%)	269	0	4	9	18	89	15	20.5	135
0.005 m (%)	269	0	0	2	7	72	8	15	191
0.001 M (%)	257	0	2	5	9	72	10	17	164
0.001 m (%)	257	0	0	0	3	57	5	11.5	234
CBR (%)	1,533	1	16	30	65	158	42.3	32.5	77

* Key to abbreviations and acronyms used for features can be found in Notation section.

† Atterberg limits for cohesive soils only.

** Depth below grade level including pavement thickness, if present.

†† Standard CE 55 compaction (DoD 1964).

Comparison with Published Datasets

The range and distribution of the features were compared to existing references in the literature to get a sense of how well the data represented what might be expected for naturally deposited soils. One report that proved particularly valuable for this task was *Statistical Analysis and Variability of Pavement Materials* by Freeman and Grogan (1997), a compilation of numerous literature references containing information on the statistical averages and distributions for a variety of soil parameters. Of particular interest were the material properties collected for “residual fine-grained soil deposits,” which may be a close representation of undisturbed soil properties in potential OLS sites. The distributions of the soil properties for the entire database (Table 4) and for the CBR-only subset (Table 5) are essentially the same, so the following analysis uses all of the cases in the full database.

Comparison plots of the database entries and the literature citations were made for 13 data fields. The parameters selected represent those for which data were available in Freeman and Grogan (1997) and a non-trivial amount of complete records was available in the full database. Comparisons were made for specific gravity, liquid limit, plastic limit, plasticity index, CE 55 optimum moisture content, CE 55 maximum dry density, gravimetric moisture content, field California bearing ratio, field dry density, and percent passing the ¾ inch, #4, #40, and #200 sieves. The comparison plots for field CBR, gravimetric moisture content, field dry density, plasticity index, and percent passing the #200 sieve are shown in Figures 6–10. The entire suite of plots for all 13 parameters is given in Appendix C. The plots illustrate the distribution of database records as individual points. Each point was horizontally “jittered” by a random amount to allow a clearer view of denser areas within the range than would be possible with a single line of points. The vertical scale was not modified in any way. Three separate bands of points are provided in each chart, representing records: 1) labeled as *Subgrade* pavement layer, 2) labeled as *Base* or *Subbase* pavement layers, and 3) all records in the database. Note that not all records in the database contain entries for the layer data field. These unlabeled records and the labeled ones are both included in the band of points labeled *All*.

For comparison, “box and whisker” plot representations of reported parameter values collected from the literature by Freeman and Grogan (1997) are shown alongside the database points. Each box and whisker plot

represents a separate citation that reported a mean and standard deviation.

Figure 11 provides an explanation of how the elements of the box and whisker plots represent mean and variability. Sources for each box and whisker plot are indicated by a letter, with the corresponding citation given in Table 6. The values from the literature represent the variability within a single lot of construction material. In plotting the reported variability, we assumed that all parameters were normally distributed. The citations are broken down into three categories as reported by Freeman and Grogan. Plots labeled *Natural Soil Deposits* represent "residual fine-grained soil deposits" from the literature, presumably from soils with little to no deliberate modification from their natural state. Plots labeled *Engineered Fill* represent compacted subgrade soils. Plots labeled *Subbase & Base* represent the select construction material typically used for building these pavement layers.

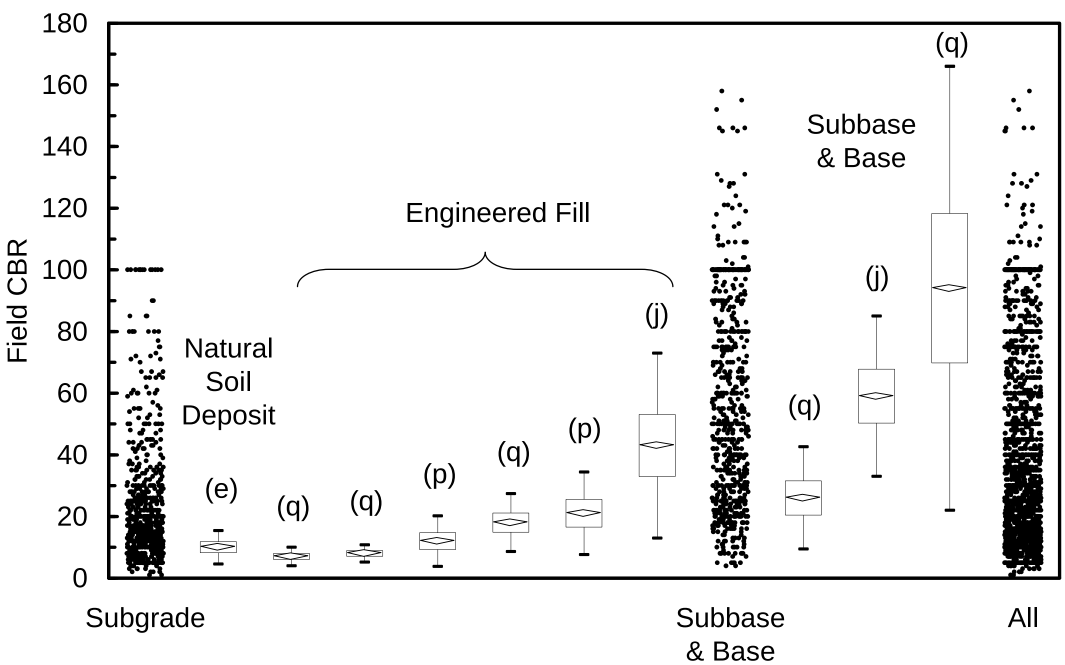

Figure 6. Comparison of database records and literature reports of field California bearing ratio.

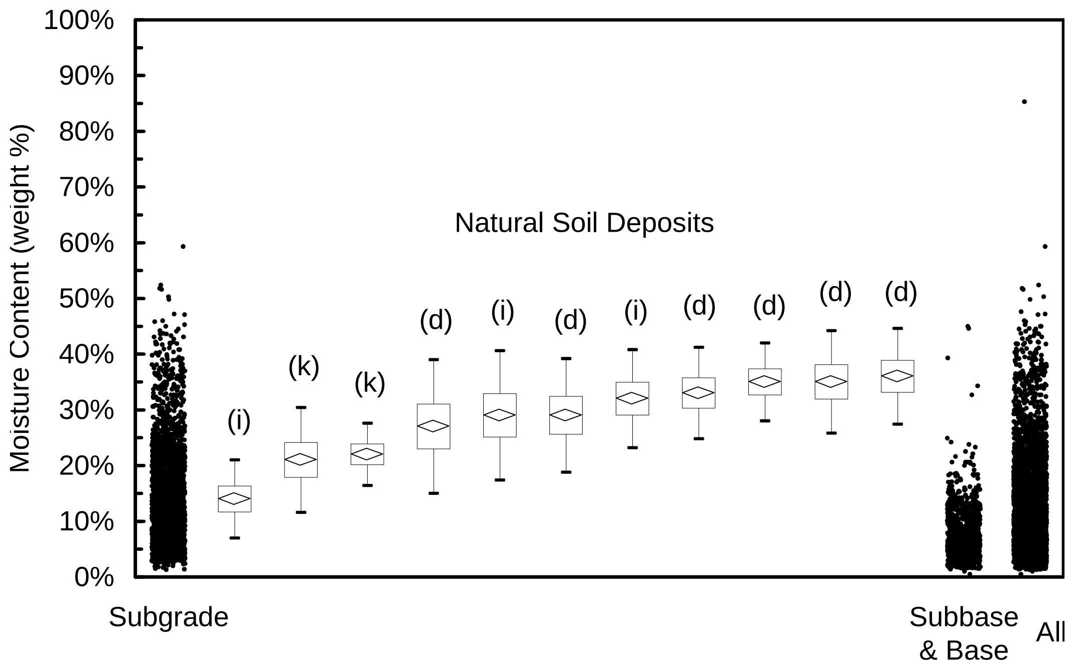

Figure 7. Comparison of database records and literature reports of gravimetric moisture content.

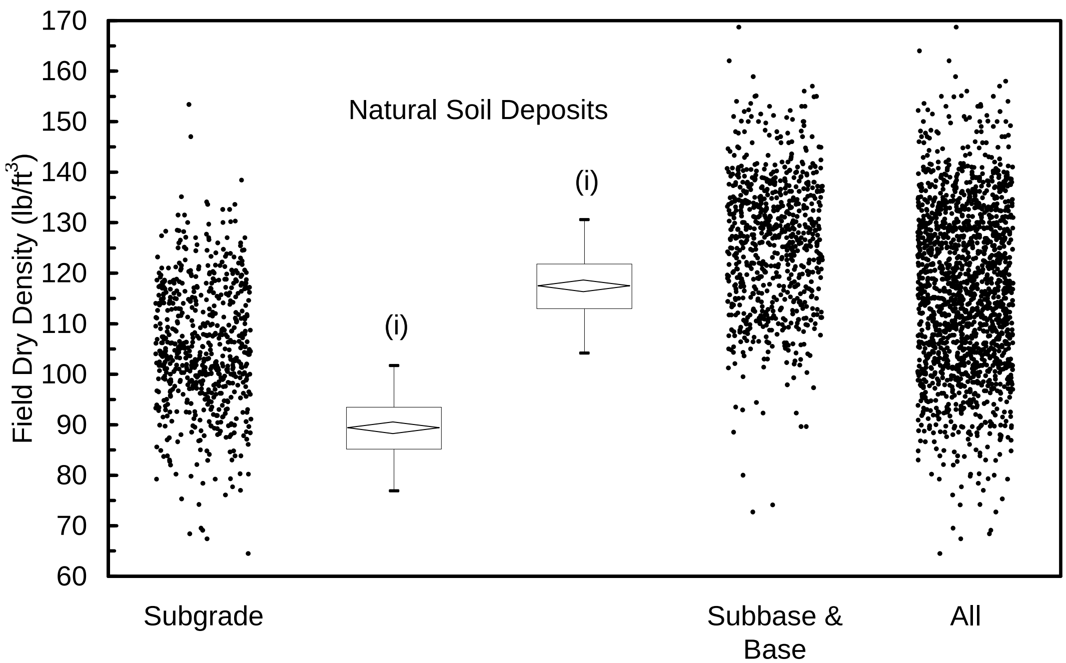

Figure 8. Comparison of database records and literature reports of field dry density.

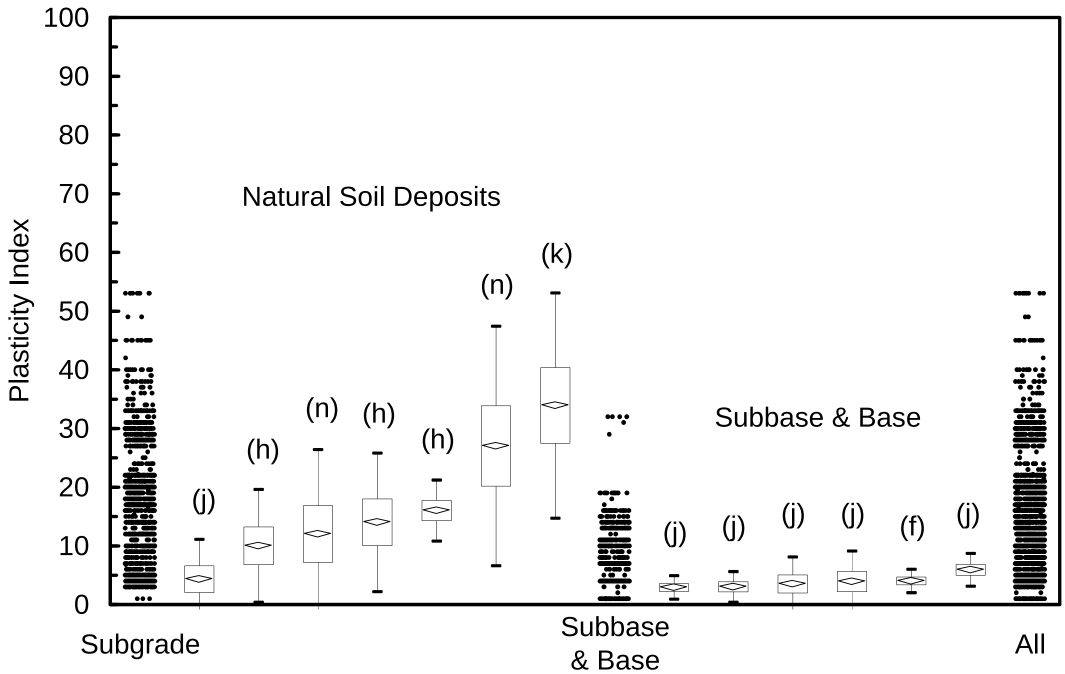

Figure 9. Comparison of database records and literature reports of plasticity index.

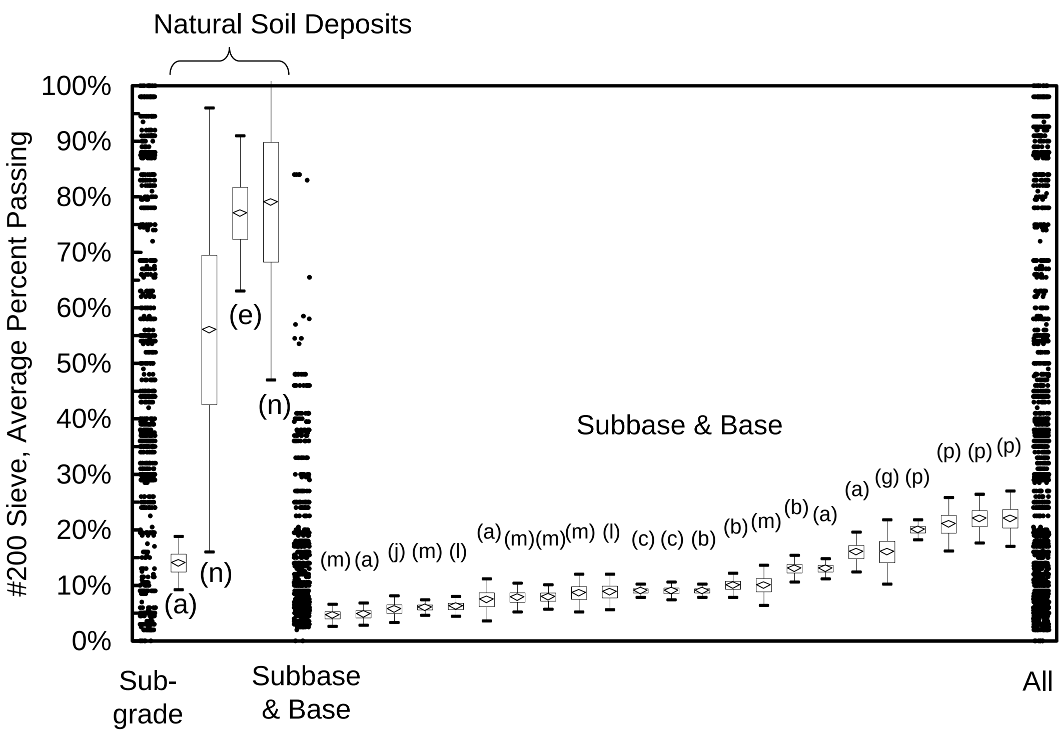

Figure 10. Comparison of database records and literature reports of average percent passing the #200 sieve.

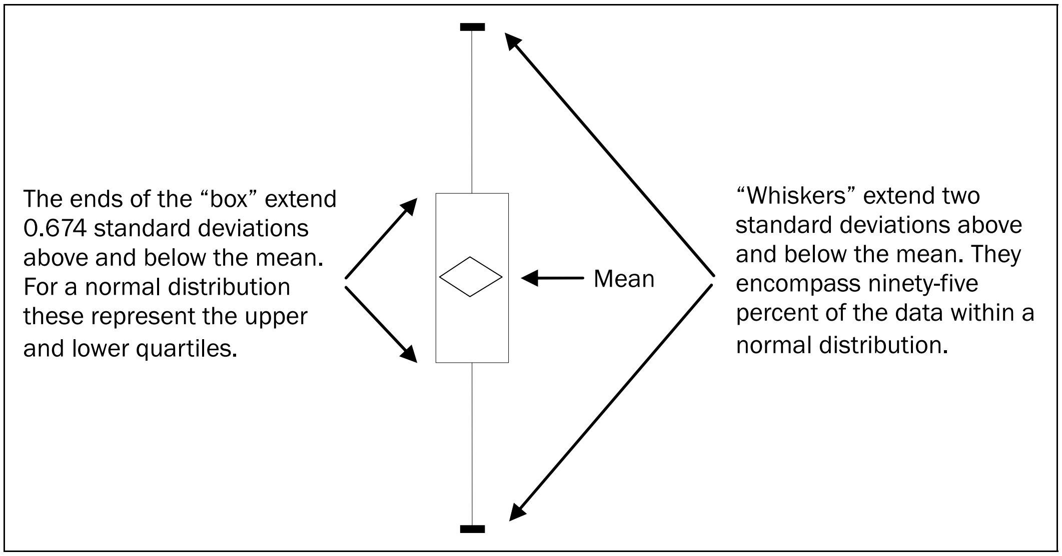

Figure 11. Key to box and whisker plot elements.

Table 6. Key to literature sources of box and whisker plot data.

Key	Reference
a	Auff and Choummanivong (1994)
b	Auff and Laksmanto (1994)
c	Auff and Yeo (1992)
d	Fredlund and Dahlman (1972)
e	Hampton et al. (1962)
f	Ingles (1972)
g	Kelley (1969)
h	Kennedy et al. (1975)
i	Krahn and Fredlund (1983)
j	Mitchell et al. (1977)
k	Schultze (1972)
l	Sherman (1971)
m	State of California (1967)
n	Wahls and Futrell (1966)
o	Willenbrock (1974)
p	Yeo and Auff (1995)
q	Yoder and Witczak (1975)

Representing the variability of the parameters from the literature sources with a normal distribution was thought to be reasonable, because each citation characterized the variability within a single lot of material. Essentially, for each instance, the true value for that single lot should be bracketed by numerous sample estimates containing a random measurement error that is distributed normally.* For the aggregated values for a variety of soils from various locations and conditions, though, the distribution for a parameter may take different shapes. This can be seen by looking at the distributions for different numerical fields in Appendix B. For example, all the cases in the database for moisture content exhibit a log-normal distribution when taken together (Fig. B20) . Therefore, even though some parameters in the database demonstrated non-normal distributions overall, the single lot values reported in the literature could be represented most reasonably with a normal distribution. In all instances, the resulting upper and lower quartile ($\pm 0.674\ \sigma$) limits of the "box" remained within plausible ranges of the measurement scales. However, for a few instances, the $\pm 2\sigma$ "whiskers" extended beyond the limits of the measurement scale. For liquid limit and plasticity index, some extended below 0%, and for the percent passing the #40 and #200 sieves, some extended above 100%.

Looking at the comparison plots reveals significant differences between the parameters for natural soils and select materials, in both the database records and the reported distributions in the literature. The select base and subbase materials clearly show the effect that standards and quality control have on several important properties. The select pavement layers exhibit higher strengths (Fig. 6), lower natural moisture contents (Fig. 7Figure 7), higher densities (Fig. 8), lower plasticity (Fig. 9Figure 9), and lower percent fines (Fig. 10) than the subgrade and natural soils. In general, the subgrade database records reflect these trends and cover the full ranges of natural soil properties reported in the literature quite well. This demonstrated the value of collecting in situ measurements and not relying on acceptance test measurements for select materials that may not represent the expected ranges for natural soil properties.

* An exception to this can occur when a measurement occurs near the "edge" of a valid sample space and the "measured" values are limited to those that are physically possible. For example, measuring the moisture content of a very dry soil could result in many measurements of zero, skewing the distribution in the negative direction or resulting in a false bimodal distribution.

Therefore, despite the reliance on collecting the data from airfield pavement testing, we felt reasonably confident that the database covered the range of conditions that one might expect to find in unimproved locations suitable for opportune landing sites. The inclusion of a thorough representation of marginal OLS materials, important for predicting unsuitable OLS (a correct non-OLS), will be assured through the companion cone index database mentioned earlier (Diemand et al., in progress).

5 Summary and Conclusion

A unique worldwide database of well-documented in situ CBR measurements and associated soil properties was compiled for use in generating soil strength prediction schemes. Among the objectives in assembling the dataset was to incorporate as many USCS soil types as possible—representative of the relative prevalence of these soil types worldwide—and focus specifically on geotechnical parameters that characterize engineering behavior, including actual field CBR measurements. Further goals were to cover the range of conditions typical for naturally deposited soils and incorporate as much diversity as possible to reflect the wide variety of environments in which they form. Finally, efforts were taken to ensure a reliable and high-quality dataset, based on field investigations that utilized consistently applied standard test methods.

The resulting database contains more than 4,500 entries, with data fields relating to soil type, grain size distribution, Atterberg limits, field-measured density and moisture content, soil strength, specific gravity, optimum moisture–density relationship, sampling locations and dates, geomorphology, and data source reference citations. The distribution of the measurements in the database fall within the range of published distributions of the numeric parameters for natural soils reported in the literature, and the database includes a wide variety of USCS soil types.

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Appendix A: Database Field Descriptions

N = numerical feature *C = categorical feature*
O = ordinal feature *B = binary feature*

OLS Data Point # *{N}*
Specific ID number given to each line of data as a unique identifier in the database.

JRAC Soil # *{N}*
Specific ID number given to each unique soil that was identified in the Joint Rapid Airfield Construction program's database (Berney and Wahl 2007).

Test or Sample Date *{N}*
Date on which measurements or tests were performed.

Report # *{C}*
Report Date *{N}*
Report Title *{C}*
Citation information for source of soil test data.

Country Code (ISO-3166) *{C}*
Standard two-letter ID code for country in which test site is located (ISO 2005).

Location *{C}*
Geographic location of test site (name of military base, town/state, airfield name, etc.).

Test Station *{C}*
Location or ID for test site within the geographic location given above (test pit #, location #, station on runway/taxiway, etc.). Corresponds with the notation given in the report source.

Layer *{O}*

Layer in the pavement structure that the data has come from—used to distinguish engineered materials from more naturally occurring ones. Categories are *Base* (high quality material placed directly beneath the pavement), *Subbase* (lower quality select material placed below the base course), and *Subgrade* (natural soil found in place, may be compacted but otherwise unmodified).

Landform *{C}*

The category of landform based on slope, relief, and relation to surrounding lands for the general area surrounding the test site. Hierarchical categories based on van Engelen and Wen (1995) include:

- *L* *Level Land*
  - *LP* *Plains*
  - *LL* *Plateaux*
  - *LD* *Depressions*
  - *LF* *Low-gradient footslopes*
  - *LV* *Valley floors*
- *S* *Sloping Land*
  - *SM* *Medium-gradient mountains*
  - *SH* *Medium-gradient hills*
  - *SE* *Medium-gradient escarpment zone*
  - *SR* *Ridges*
  - *SU* *Mountainous highland*
  - *SP* *Dissected plains*
- *T* *Steep Land*
  - *TM* *High-gradient mountains*
  - *TH* *High-gradient hills*
  - *TE* *High-gradient escarpment zone*
  - *TV* *High-gradient valleys*
- *C* *Lands with Composite Landforms*
  - *CV* *Valleys*
  - *CL* *Narrow plateaus*
  - *CD* *Major depressions*

Lithology of Parent Material *{C}*

Category of rock type that forms the basis for the soil, primarily based on geology and mineralogy. Hierarchical categories based on van Engelen and Wen (1995) include:

- *I* — *Igneous rock*
  - *IA* — *Acid Igneous*
    - *IA1* — *Granite*
    - *IA2* — *Grano-Diorite*
    - *IA3* — *Quartz-Diorite*
    - *IA4* — *Rhyolite*
  - *II* — *Intermediate Igneous*
    - *II1* — *Andesite, Trachyte, Phonolite*
    - *II2* — *Diorite-Syenite*
  - *IB* — *Basic Igneous*
    - *IB1* — *Gabbro*
    - *IB2* — *Basalt*
    - *IB3* — *Dolerite*
  - *IU* — *Ultrabasic Igneous*
    - *IU1* — *Peridotite*
    - *IU2* — *Pyroxenite*
    - *IU3* — *Ilmenite, Magnetite, Ironstone, Serpentine*
- *M* — *Metamorphic rock*
  - *MA* — *Acid Metamorphic*
    - *MA1* — *Quartzite*
    - *MA2* — *Gneiss, Migmatite*
    - *MA3* — *Slate, Phyllite (peltic rocks)*
    - *MA4* — *Schist*
  - *MB* — *Basic Metamorphic*
    - *MB1* — *Slate, Phyllite (peltic rocks)*
    - *MB2* — *Schist*
    - *MB3* — *Gneiss rich in ferro-magnesian minerals*
    - *MB4* — *Metamorphic Limestone (Marble)*
- *S* — *Sedimentary rock*
  - *SC* — *Classic Sediments*

- *SC1* *Conglomerate, Breccia*
- *SC2* *Sandstone, Greywacke, Arkose*
- *SC3* *Siltstone, Mudstone, Claystone*
- *SC4* *Shale*
- *SC5* *Ironstone*

SO *Organic*

- *SO1* *Limestone, other carbonate rocks*
- *SO2* *Marl and other mixtures*
- *SO3* *Coals, Bitumen, & related rocks*

SE *Evaporites*

- *SE1* *Anhydrite, Gypsum*
- *SE2* *Halite*

Deposition Type *{C}*

Method of natural deposition for soil material at the test site. Categories for unconsolidated sediments based on van Engelen and Wen (1995) include:

- *UF* *Fluvial*
- *UL* *Lacustrine*
- *UM* *Marine*
- *UC* *Colluvial*
- *UE* *Eolian (Aeolian)*
- *UG* *Glacial*
- *UP* *Pyroclastic*
- *UO* *Organic*

Depth to Water Table *{N}*

Depth in feet to natural ground water from grade level at test site.

Soil Type, USCS *{C}*
Soil classification according to the Unified Soil Classification System. Twenty-six possible entries include:

GW	*Well-graded gravel*
GP	*Poorly graded gravel*
GM	*Silty gravel*
GC	*Clayey gravel*
SW	*Well-graded sand*
SP	*Poorly graded sand*
SM	*Silty sand*
SC	*Clayey sand*
ML	*Low-compressibility silt*
CL	*Lean clay*
OL	*Organic silt or clay*
MH	*High-compressibility silt*
CH	*Fat clay*
OH	*Organic silt or clay*
Pt	*Peat*
CL-ML	*Silty clay*
GW-GM	*Well-graded gravel with silt*
GW-GC	*Well-graded gravel with clay*
GP-GM	*Poorly graded gravel with silt*
GP-GC	*Poorly graded gravel with clay*
GC-GM	*Silty, clayey gravel*
SW-SM	*Well-graded sand with silt*
SW-SC	*Well-graded sand with clay*
SP-SM	*Poorly graded sand with silt*
SP-SC	*Poorly graded sand with clay*
SC-SM	*Silty, clayey sand*

Alternate Soil Type *{C}*
Alternate Soil System *{C}*
Soil classification with non-USCS system.

Soil Description *{C}*

Remarks on descriptive soil characteristics included with test data (textural description, color, etc.).

Clay Mineralogy *{C}*

Dominant type of mineral in the clay fraction of the soil. Can have a large influence on mechanical behavior for certain minerals. Categories based on van Engelen and Wen (1995) include:

AL	*Allophane*
CH	*Chloritic*
IL	*Illitic*
IN	*Interstratified or Mixed*
KA	*Kaolinitic*
MO	*Montmorillonitic*
SE	*Sesquioxidic*
VE	*Vermiculitic*

Specific Gravity *{N}*

Relative density of soil particles compared to water.

Sample Depth Below Grade *{N}*

Depth in inches from grade level at site where testing was performed, including pavement thickness (if present).

Plastic or Non-Plastic *{B}*

Indicates whether the material passing the #40 sieve exhibits plastic behavior at some moisture content (e.g. clay) or does not (e.g. sand). During the data entry process, sources that reported numerical values for liquid limit, plastic limit, and plasticity index were entered as *P*. Sources for which the plasticity was explicitly reported as "non-plastic" were entered as *NP*. No entry in this field indicates that the source reported no liquid limit, plastic limit, or plasticity values nor did it provide an explicit indication that the soil was non-plastic.

LL *{N}*

Liquid Limit of the soil in percent. The gravimetric moisture content at an arbitrary limit between the liquid and plastic states of consistency where the soil begins to exhibit a liquid behavior and will flow under its own weight.

PL *{N}*

Plastic Limit of the soil in percent. The gravimetric moisture content at an arbitrary limit between the plastic and semi-solid states of consistency where the soil begins to exhibit a plastic behavior and will deform under pressure without crumbling.

PI *{N}*

Plasticity Index of the soil in percent. The numerical difference between the liquid limit and plastic limit of the soil. A larger plasticity index indicates a soil that is more likely to exhibit plastic behavior.

Compactive Effort *{N}*

Amount of energy in foot-pounds per cubic foot put into compacting a unit volume of soil in preparing a laboratory sample. Different test standards result in different compactive efforts, influencing the shape and location of the compaction curve relating soil moisture to density.

Molding Moisture Content *{N}*

Gravimetric moisture content of the soil in percent used in preparing a laboratory sample.

Dry Density (laboratory) *{N}*

Density of the soil in pounds per cubic foot used in preparing a laboratory sample. The dry density includes only the oven-dry mass of soil particles present in a unit volume, not any of the adsorbed or free water that may exist contributing to the sample’s moisture content.

Optimum Moisture Content and Max. Density *{B}*

Indication of whether the previous three measurements relate the peak on the moisture-density curve for that compaction energy (Y) or simply a single data point from a Proctor test on the moisture-density curve (N).

Unsoaked CBR (laboratory) *{N}*
Soaked CBR (laboratory) *{N}*

Laboratory measurement of the California bearing ratio in percent. The soil sample is prepared at a given compaction energy, molding moisture content, and dry density. It is then tested (unsoaked) or allowed to soak in water for four days to reach a nearly saturated moisture condition.

Moisture Content as Tested (weight %) *{N}*
Moisture Content as Tested (volumetric %) *{N}*
Moisture content of the soil tested in percent. Gravimetric moisture content is the weight of absorbed and free water in the soil that can be driven off by oven drying divided by the dry soil weight. Volumetric moisture content is the volume of absorbed and free water relative to the total volume of soil.

Trafficability Cone Index (CI) *{N}*
Index test of soil strength used for ground vehicle mobility. Performed by pushing a standard rod with a 30° cone-shaped tip through the soil surface and recording the reaction force in pounds per square inch. The test is performed on soil that is undisturbed.

Remolding Index *{N}*
Ratio of the trafficability cone index for undisturbed soils to those that have been remolded. This gives some indication of the change in vehicle mobility after many passes have occurred.

DCP Index (dynamic cone penetrometer) *{N}*
Dynamic cone penetrometer index test for soil strength, measured in millimeters per blow. Performed by using a sliding weight, repeatedly dropped from a constant height, to dynamically drive a 60° conically tipped rod through the soil. The distance of penetration is measured versus the number of blows and has been correlated with CBR (Webster et al. 1992).

Field CBR *{N}*
In situ field measurement of the California bearing ratio in percent.

Field Dry Density *{N}*
Field Wet Density *{N}*
Density of the soil measured in situ in the field in pounds per cubic foot. The dry density includes only the oven-dry mass of soil particles present in a unit volume—not any of the absorbed or free water that may exist contributing to the sample's moisture content. The wet density includes both the oven-dry mass of soil particles present in a unit volume and any of the absorbed or free water that may exist contributing to the sample's moisture content.

¾ inch Sieve, Maximum Percent Passing *{N}*
¾ inch Sieve, Minimum Percent Passing *{N}*
⅜ inch Sieve, Maximum Percent Passing *{N}*
⅜ inch Sieve, Minimum Percent Passing *{N}*
#4 Sieve, Maximum Percent Passing *{N}*
#4 Sieve, Minimum Percent Passing *{N}*
#10 Sieve, Maximum Percent Passing *{N}*
#10 Sieve, Minimum Percent Passing *{N}*
#40 Sieve, Maximum Percent Passing *{N}*
#40 Sieve, Minimum Percent Passing *{N}*
#100 Sieve, Maximum Percent Passing *{N}*
#100 Sieve, Minimum Percent Passing *{N}*
#200 Sieve, Maximum Percent Passing *{N}*
#200 Sieve, Minimum Percent Passing *{N}*
0.005 mm, Maximum Percent Passing *{N}*
0.005 mm, Minimum Percent Passing *{N}*
0.001 mm, Maximum Percent Passing *{N}*
0.001 mm, Minimum Percent Passing *{N}*
Gravimetric percentage of particles in a soil smaller than a certain size, determined by shaking coarse soil particles through a stack of standard size sieves. For particles finer than the #200 sieve, this is determined using a hydrometer by taking readings of a mixture of fine soil particles and water—with decreasingly smaller particles settling out of suspension over time. Both minimum and maximum are recorded due to soil data being grouped into "families" of similar soils in many of the airfield pavement evaluation reports and the gradation plots resulting in bands of sizes rather than distinct curves. If minimum equals maximum, then data were recorded from a single curve (or a converging band).

Roundness, Gravel {N}
Roundness, Sand {N}
Standard measure of the relative angularity of a soil particle's edges and corners, determined visually (Krumbein and Sloss 1951).

Sphericity, Gravel {N}
Sphericity, Sand {N}
Standard measure of the aspect ratio of a soil particle's dimensions, determined visually (Krumbein and Sloss 1951).

Remarks {C}
Catch-all for any remarks associated with test data.

Appendix B: Detailed Distribution of Selected Fields in the Full Database

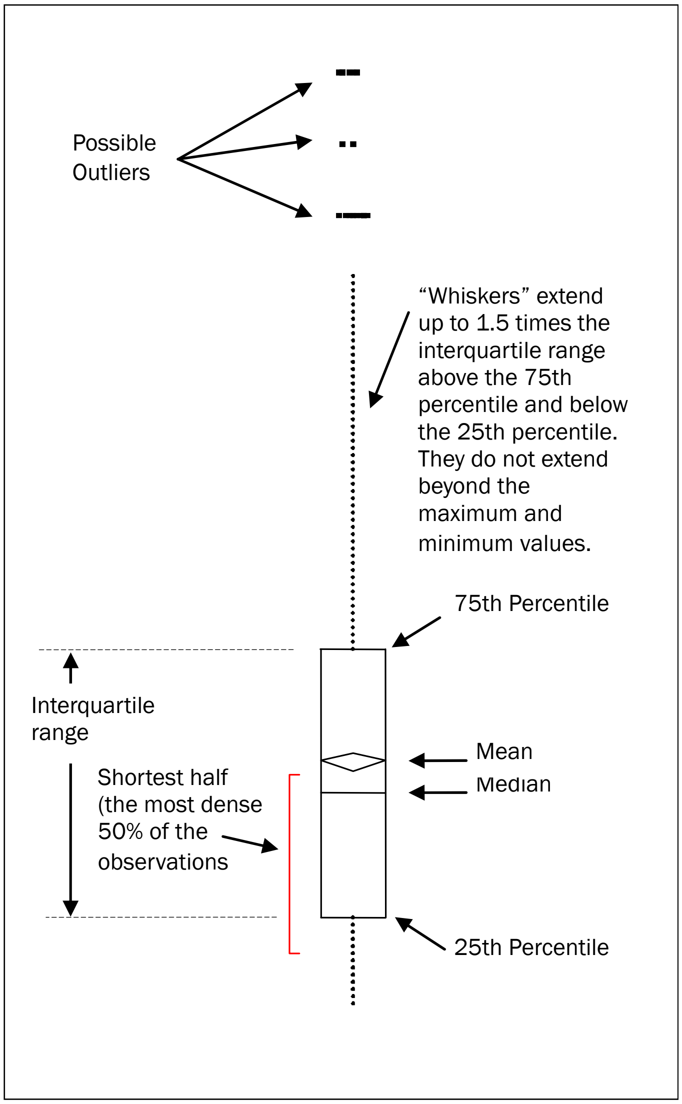

Figure B1. Key to outlier box plot elements.

Test or sample date

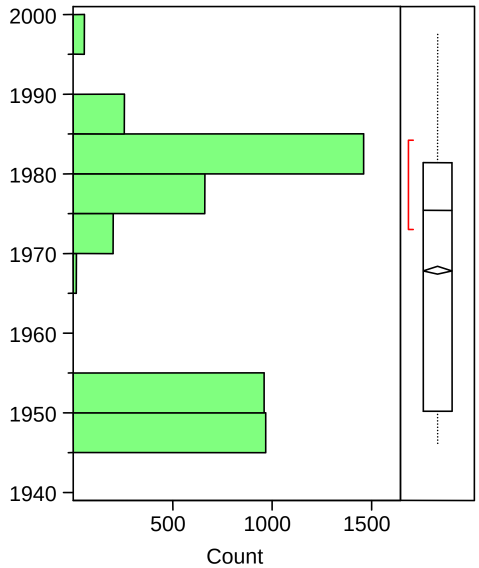

Figure B2. Distribution of records by "test or sample date" field.

Table B1. Moments and quantiles for "test or sample date" field.

Moments and Quantiles	
Number Records	4592
Number Missing	0
Mean	November 1967
Median	May 1975
Earliest	October 1945
Latest	September 1997

Report date

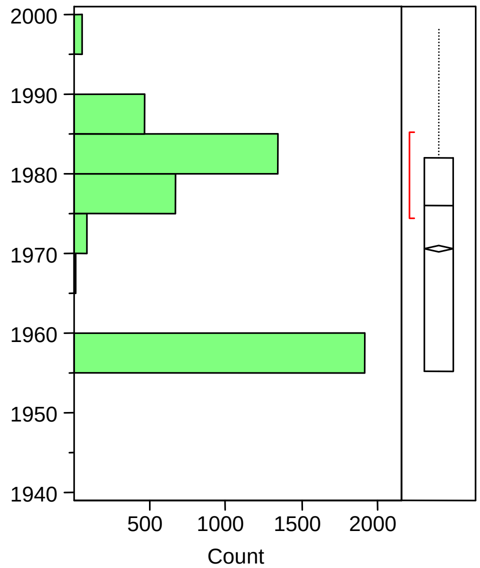

Figure B3. Distribution of records by "report date" field.

Table B2. Moments and quantiles for "report date" field.

Moments and Quantiles	
Number Records	4592
Number Missing	0
Mean	July 1970
Median	February 1976
Earliest	April 1955
Latest	June 1998

Report title

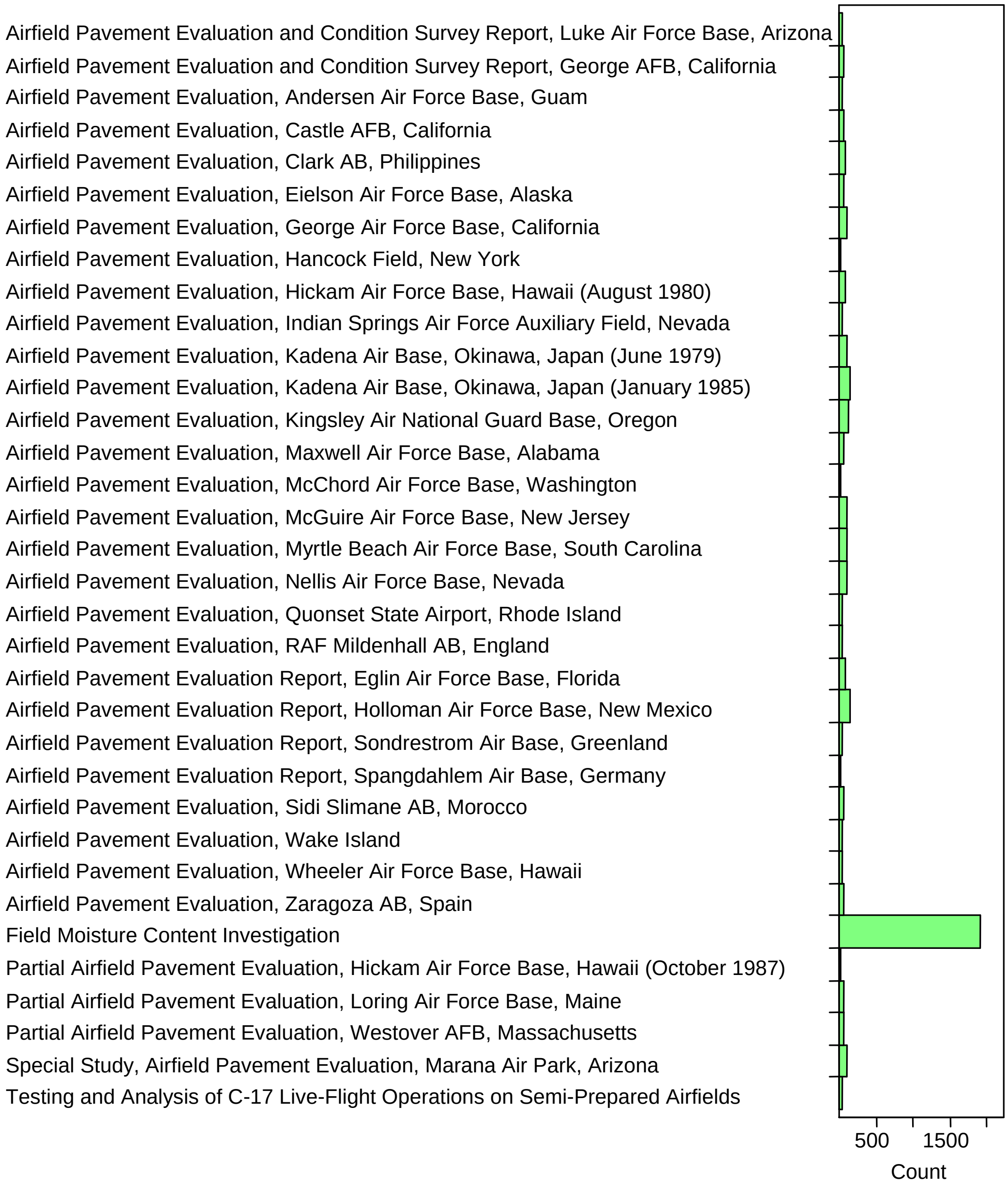

Figure B4. Distribution of records by “report title” field.

Table B3. Distribution of records by “report title” field.

Report Title	Count	Percent
Airfield Pavement Evaluation and Condition Survey Report, Luke Air Force Base, Arizona	51	1.1%
Airfield Pavement Evaluation and Condition Survey Report, George AFB, California	69	1.5%
Airfield Pavement Evaluation, Andersen Air Force Base, Guam	56	1.2%
Airfield Pavement Evaluation, Castle AFB, California	80	1.7%
Airfield Pavement Evaluation, Clark AB, Philippines	103	2.2%
Airfield Pavement Evaluation, Eielson Air Force Base, Alaska	71	1.5%
Airfield Pavement Evaluation, George Air Force Base, California	121	2.6%
Airfield Pavement Evaluation, Hancock Field, New York	38	0.8%
Airfield Pavement Evaluation, Hickam Air Force Base, Hawaii	85	1.9%
Airfield Pavement Evaluation, Indian Springs Air Force Auxiliary Field, Nevada	61	1.3%
Airfield Pavement Evaluation, Kadena Air Base, Okinawa, Japan (June 1979)	125	2.7%
Airfield Pavement Evaluation, Kadena Air Base, Okinawa, Japan (January 1985)	152	3.3%
Airfield Pavement Evaluation, Kingsley Air National Guard Base, Oregon	140	3.0%
Airfield Pavement Evaluation, Maxwell Air Force Base, Alabama	78	1.7%
Airfield Pavement Evaluation, McChord Air Force Base, Washington	41	0.9%
Airfield Pavement Evaluation, McGuire Air Force Base, New Jersey	117	2.5%
Airfield Pavement Evaluation, Myrtle Beach Air Force Base, South Carolina	108	2.4%
Airfield Pavement Evaluation, Nellis Air Force Base, Nevada	107	2.3%
Airfield Pavement Evaluation, Quonset State Airport, Rhode Island	60	1.3%
Airfield Pavement Evaluation, RAF Mildenhall AB, England	57	1.2%
Airfield Pavement Evaluation Report, Eglin Air Force Base, Florida	92	2.0%
Airfield Pavement Evaluation Report, Holloman Air Force Base, New Mexico	163	3.5%
Airfield Pavement Evaluation Report, Sondrestrom Air Base, Greenland	44	1.0%
Airfield Pavement Evaluation Report, Spangdahlem Air Base, Germany	20	0.4%
Airfield Pavement Evaluation, Sidi Slimane AB, Morocco	77	1.7%
Airfield Pavement Evaluation, Wake Island	62	1.4%
Airfield Pavement Evaluation, Wheeler Air Force Base, Hawaii	61	1.3%
Airfield Pavement Evaluation, Zaragoza AB, Spain	67	1.5%
Field Moisture Content Investigation	1925	41.9%
Partial Airfield Pavement Evaluation, Hickam Air Force Base, Hawaii	41	0.9%
Partial Airfield Pavement Evaluation, Loring Air Force Base, Maine	67	1.5%
Partial Airfield Pavement Evaluation, Westover AFB, Massachusetts	74	1.6%
Special Study, Airfield Pavement Evaluation, Marana Air Park, Arizona	122	2.7%
Testing and Analysis of C-17 Live-Flight Operations on Semi-Prepared Airfields	57	1.2%
Missing	0	0.0%

Country

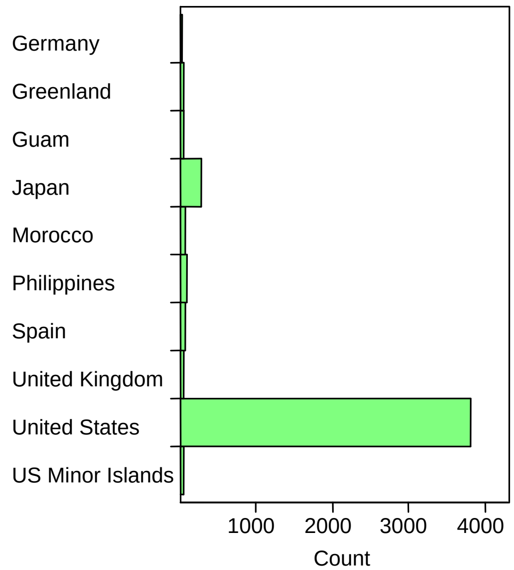

Figure B5. Distribution of records by "country" field.

Table B4. Distribution of records by "country" field.

Country	Count	Percent
Germany	20	0.4%
Greenland	44	1.0%
Guam	56	1.2%
Japan	277	6.0%
Morocco	77	1.7%
Philippines	103	2.2%
Spain	67	1.5%
United Kingdom	57	1.2%
United States	3829	83.4%
U.S. Minor Islands	62	1.4%
Missing	0	0.0%

Location

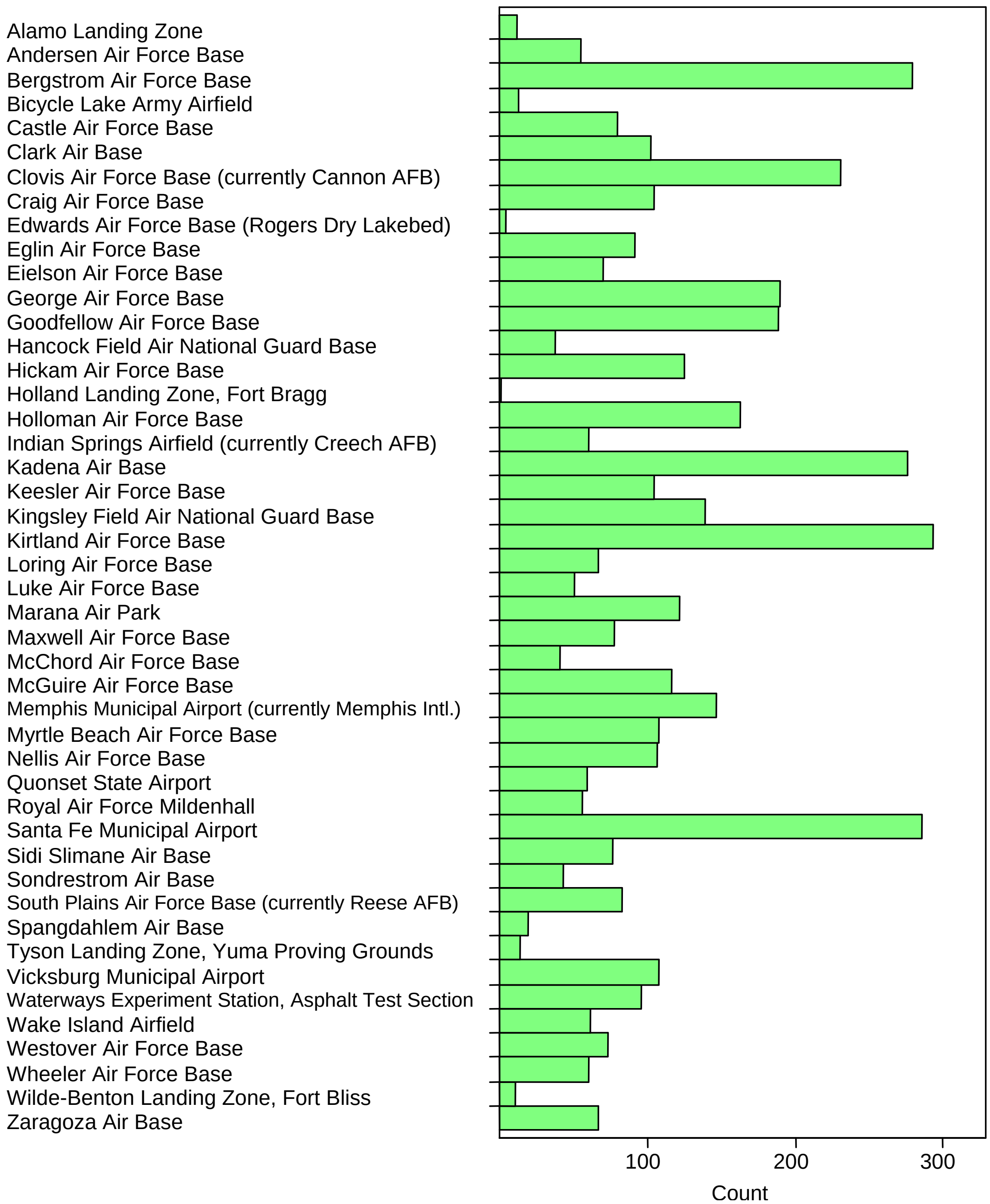

Figure B6. Distribution of records by "location" field.

Table B5. Distribution of records by "location" field.

Location	Count	Percent
Alamo Landing Zone	12	0.3%
Andersen Air Force Base	56	1.2%
Bergstrom Air Force Base	280	6.1%
Bicycle Lake Army Airfield	13	0.3%
Castle Air Force Base	80	1.7%
Clark Air Base	103	2.2%
Clovis Air Force Base (currently Cannon Air Force Base)	231	5.0%
Craig Air Force Base	105	2.3%
Edwards Air Force Base (Rogers Dry Lakebed)	5	0.1%
Eglin Air Force Base	92	2.0%
Eielson Air Force Base	71	1.5%
George Air Force Base	190	4.1%
Goodfellow Air Force Base	189	4.1%
Hancock Field Air National Guard Base	38	0.8%
Hickam Air Force Base	126	2.7%
Holland Landing Zone, Fort Bragg	1	0.0%
Holloman Air Force Base	163	3.5%
Indian Springs Airfield (currently Creech Air Force Base)	61	1.3%
Kadena Air Base	277	6.0%
Keesler Air Force Base	105	2.3%
Kingsley Field Air National Guard Base	140	3.0%
Kirtland Air Force Base	294	6.4%
Loring Air Force Base	67	1.5%
Luke Air Force Base	51	1.1%
Marana Air Park	122	2.7%
Maxwell Air Force Base	78	1.7%
McChord Air Force Base	41	0.9%
McGuire Air Force Base	117	2.5%
Memphis Municipal Airport (currently Memphis International Airport)	147	3.2%
Myrtle Beach Air Force Base	108	2.4%
Nellis Air Force Base	107	2.3%
Quonset State Airport	60	1.3%
Royal Air Force Mildenhall	57	1.2%
Santa Fe Municipal Airport	286	6.2%
Sidi Slimane Air Base	77	1.7%
Sondrestrom Air Base	44	1.0%
South Plains Air Force Base (currently Reese Air Force Base)	84	1.8%
Spangdahlem Air Base	20	0.4%
Tyson Landing Zone, Yuma Proving Grounds	15	0.3%

Location	Count	Percent
Vicksburg Municipal Airport	108	2.4%
Waterways Experiment Station, Asphalt Test Section	96	2.1%
Wake Island Airfield	62	1.4%
Westover Air Force Base	74	1.6%
Wheeler Air Force Base	61	1.3%
Wilde-Benton Landing Zone, Fort Bliss	11	0.2%
Zaragoza Air Base	67	1.5%
Missing	0	0.0%

Pavement layer

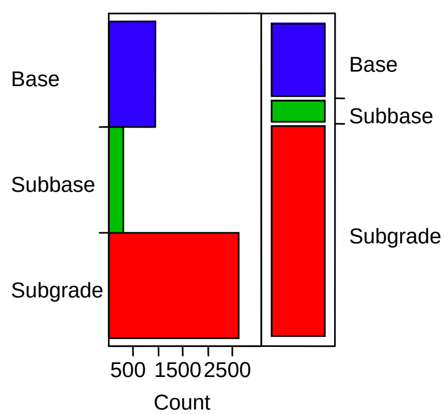

Figure B7. Distribution of records by “pavement layer” field.

Table B6. Distribution of records by “pavement layer” field.

Layer	Count	Percent
Base	940	20.5%
Subbase	298	6.5%
Subgrade	2645	57.6%
Missing	709	15.4%

Landform

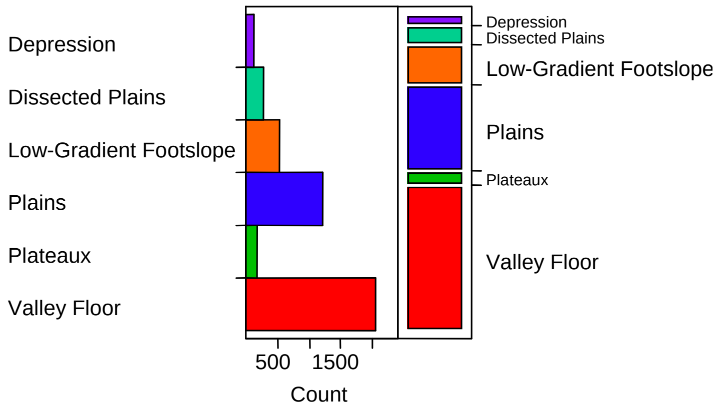

Figure B8. Distribution of records by “landform” field.

Table B7. Distribution of records by “landform” field.

Landform	Count	Percent
Depression	140	3.0%
Dissected Plains	286	6.2%
Low-Gradient Footslope	547	11.9%
Plains	1230	26.8%
Plateaux	185	4.0%
Valley Floor	2065	45.0%
Missing	139	3.0%

Lithology of parent material

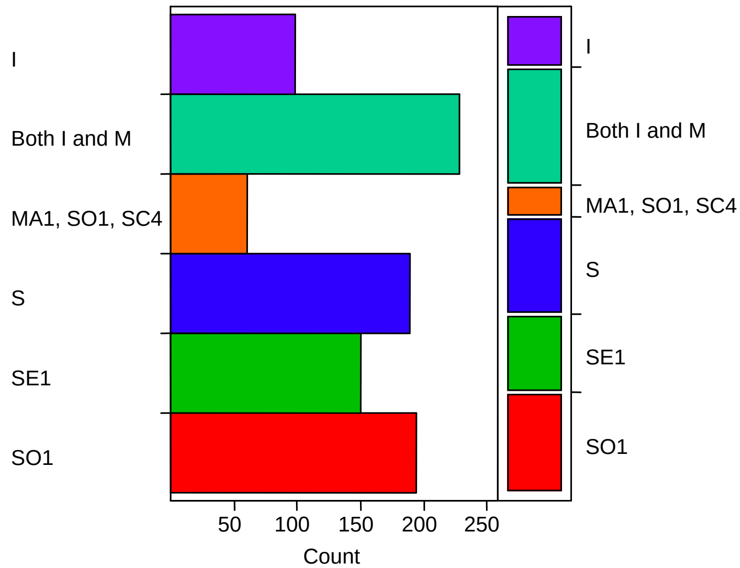

Figure B9. Distribution of records by "lithology of parent material" field.

Table B8. Distribution of records by "lithology of parent material" field.

Lithology of Parent Material	Count	Percent
Igneous rock (I)	99	2.2%
Both Igneous (I) and Metamorphic (M) rock	229	5.0%
Quartzite (MA1), Limestone and other carbonate rocks (SO1), and Shale (SC4)	61	1.3%
Sedimentary rock (S)	189	4.1%
Anhydrite, Gypsum (SE1)	151	3.3%
Limestone and other carbonate rocks (SO1)	195	4.2%
Missing	3668	79.9%

Deposition type

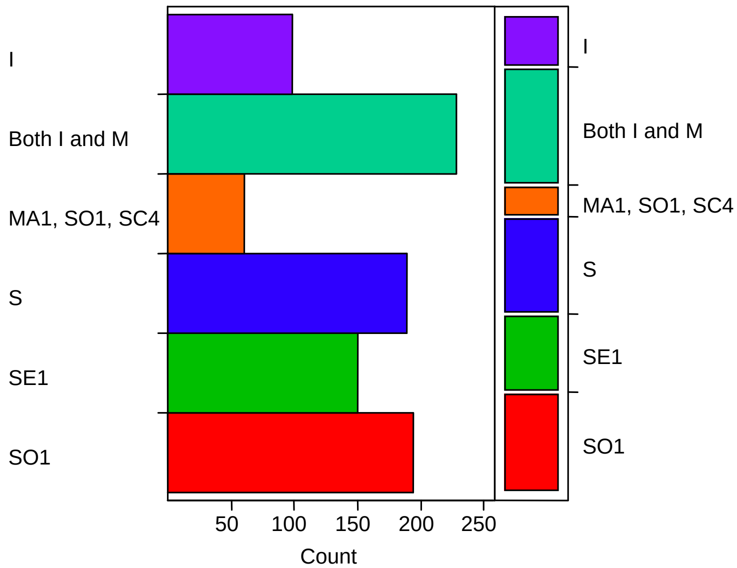

Figure B10. Distribution of records by “deposition type” field.

Table B9. Distribution of records by “deposition type” field.

Deposition Type	Count	Percent
Eolian	394	8.6%
Eolian & Marine	92	2.0%
Fluvial	1589	34.6%
Glacial	199	4.3%
Lacustrine	56	1.2%
Marine	223	4.9%
Missing	2039	44.4%

Specific gravity

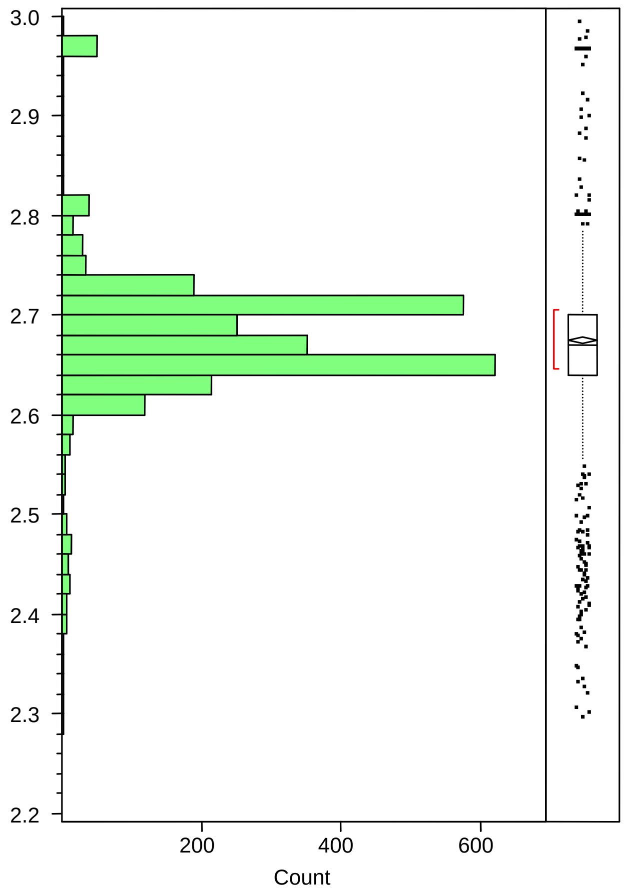

Figure B11. Distribution of records by "specific gravity" field.

Table B10. Quantiles for "specific gravity" field.

Quantiles		
100.0%	maximum	2.994
99.5%		2.966
97.5%		2.855
90.0%		2.730
75.0%	quartile	2.700
50.0%	median	2.670
25.0%	quartile	2.640
10.0%		2.620
2.5%		2.481
0.5%		2.378
0.0%	minimum	2.296

Table B11. Moments for "specific gravity" field.

Moments	
Number Records	2638
Number Missing	1954
Mean	2.675
Variance	0.005562
Standard Deviation	0.07458
Coeff. of Variation	2.788
Skewness	0.2275
Kurtosis	7.217

Sample depth below grade (inches)

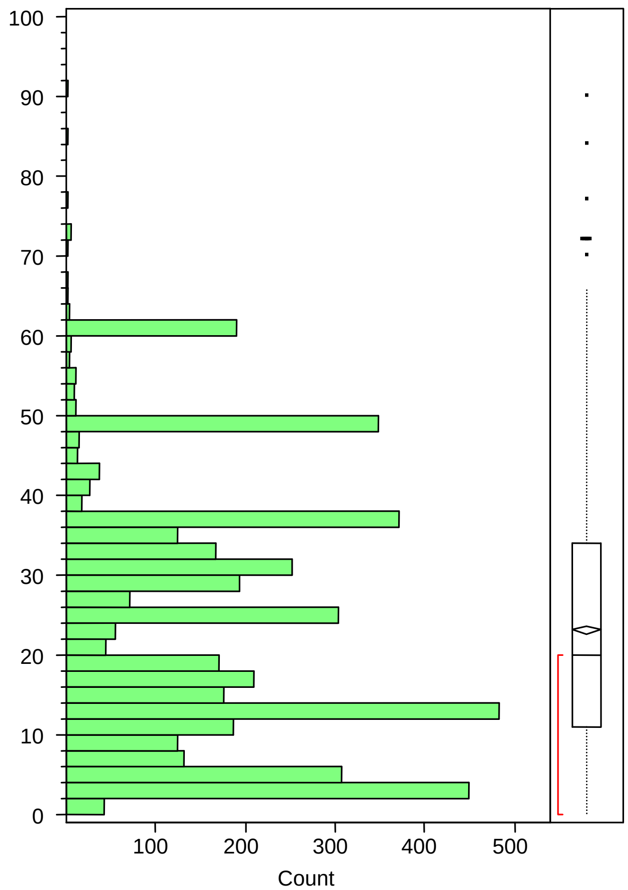

Figure B12. Distribution of records by “sample depth below grade” field.

Table B12. Quantiles for “sample depth below grade” field.

Quantiles		
100.0%	maximum	90
99.5%		61
97.5%		60
90.0%		48
75.0%	quartile	34
50.0%	median	20
25.0%	quartile	11
10.0%		3
2.5%		2
0.5%		0
0.0%	minimum	0

Table B13. Moments for “sample depth below grade” field.

Moments	
Number Records	4592
Number Missing	0
Mean	23
Variance	264
Standard Deviation	16
Coeff. of Variation	70
Skewness	0.62
Kurtosis	–0.36

Unified Soil Classification

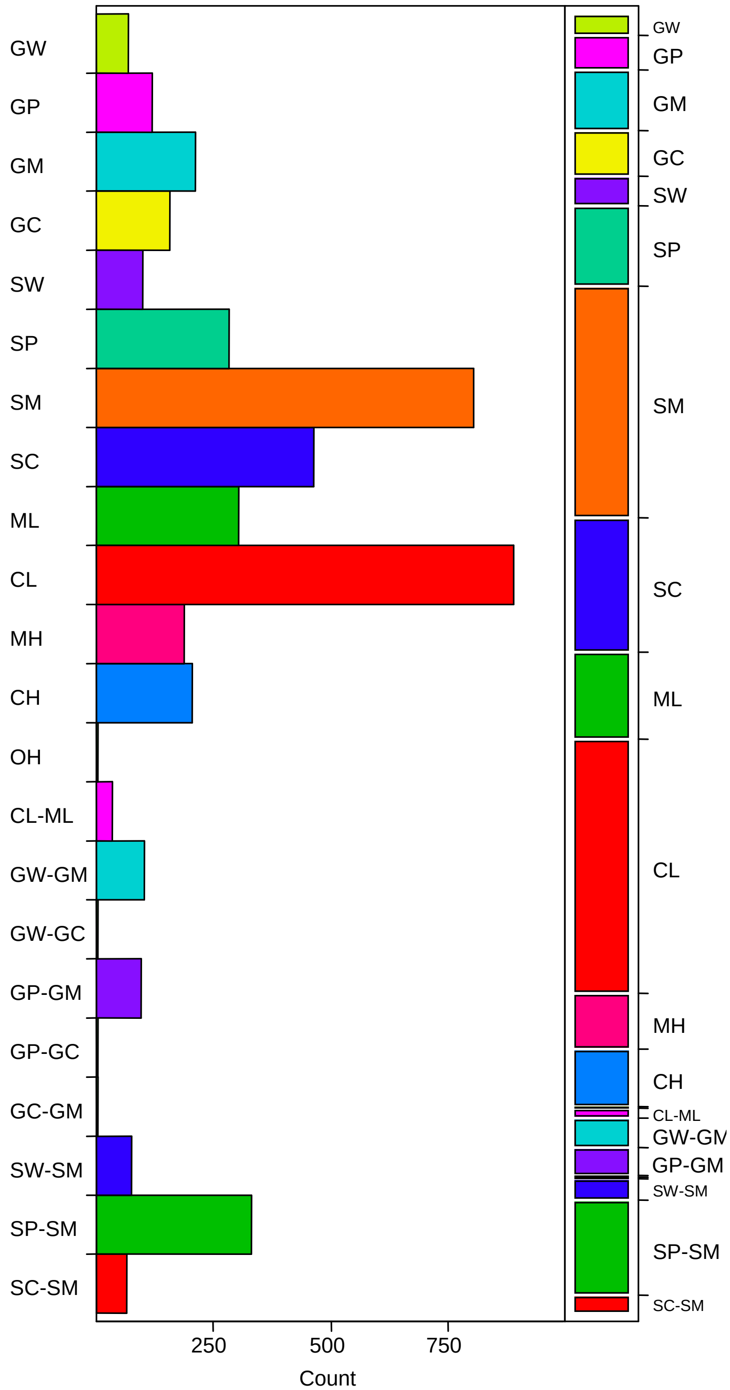

Figure B13. Distribution of records by "Unified Soil Classification" field.

Table B14. Distribution of records by "Unified Soil Classification" field.

Soil Classification	Count	Percentage
GW	71	1.5%
GP	120	2.6%
GM	214	4.7%
GC	160	3.5%
SW	101	2.2%
SP	284	6.2%
SM	807	17.6%
SC	466	10.1%
ML	304	6.6%
CL	892	19.4%
OL	0	0.0%
MH	190	4.1%
CH	205	4.5%
OH	1	0.0%
Pt	0	0.0%
CL-ML	36	0.8%
GW-GM	105	2.3%
GW-GC	1	0.0%
GP-GM	97	2.1%
GP-GC	2	0.0%
GC-GM	5	0.1%
SW-SM	75	1.6%
SW-SC	0	0.0%
SP-SM	333	7.3%
SP-SC	0	0.0%
SC-SM	67	1.5%
Missing	56	1.2%

Plastic or non-plastic

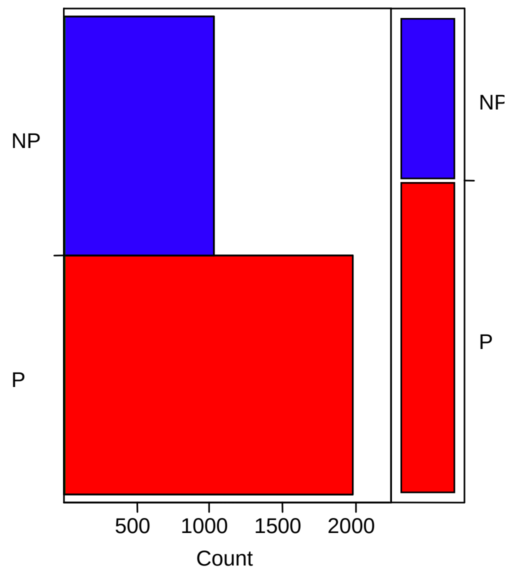

Figure B14. Distribution of records by “plastic or non-plastic” field.

Table B15. Distribution of records by “plastic or non-plastic” field.

Plastic or Non-Plastic	Count	Percent
Non-Plastic (NP)	1031	22.5%
Plastic (P)	1989	43.3%
Missing	1572	34.2%

Liquid limit (percent)

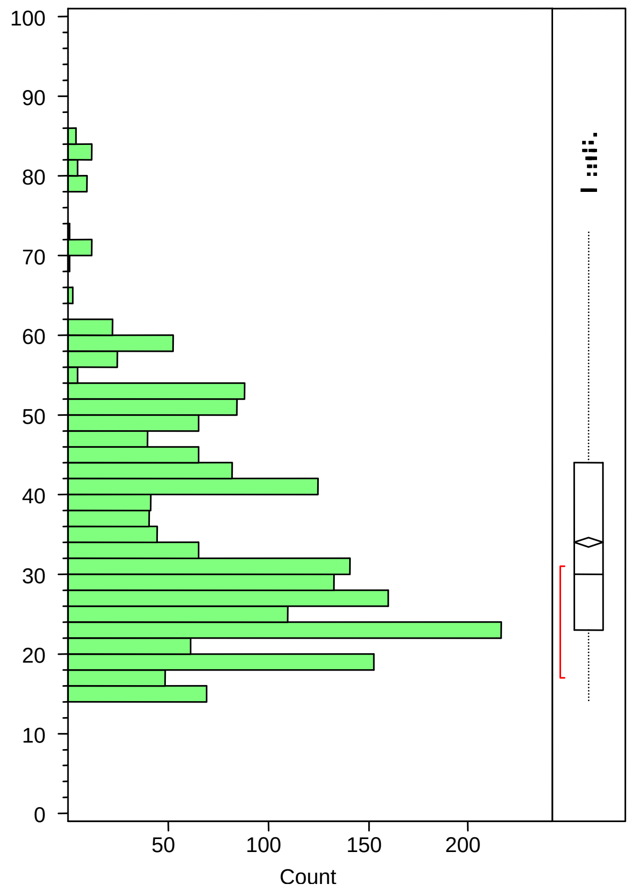

Figure B15. Distribution of records by “liquid limit” field.

Table B16. Quantiles for “liquid limit” field.

Quantiles		
100.0%	maximum	85
99.5%		83
97.5%		61
90.0%		52
75.0%	quartile	44
50.0%	median	30
25.0%	quartile	23
10.0%		18
2.5%		15
0.5%		14
0.0%	minimum	14

Table B17. Moments for “liquid limit” field.

Moments	
Number Records	1996
Number Missing	2596
Mean	34
Variance	196
Standard Deviation	14
Coeff. of Variation	41
Skewness	0.88
Kurtosis	0.53

Plastic limit (percent)

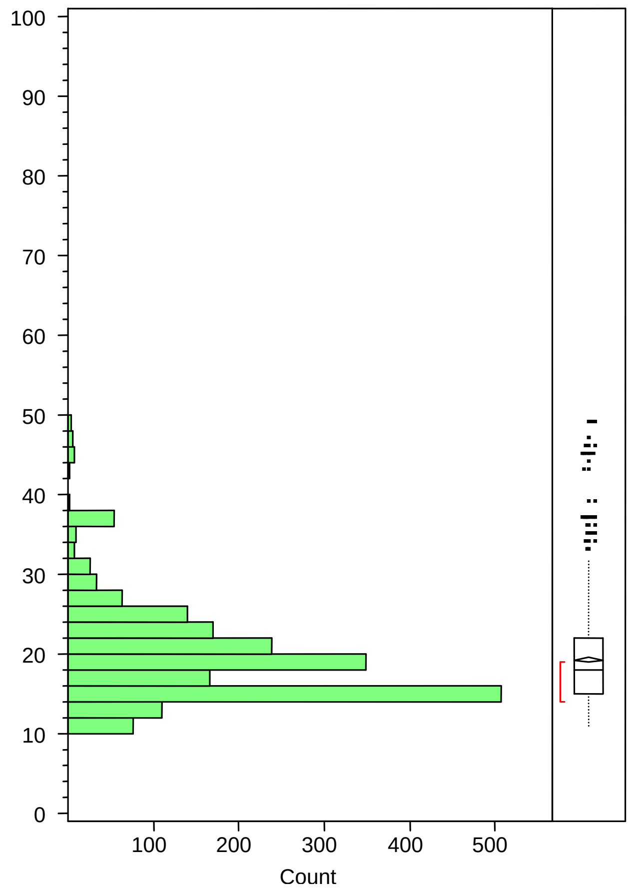

Figure B16. Distribution of records by “plastic limit” field.

Table B18. Quantiles for “plastic limit” field.

Quantiles		
100.0%	maximum	49
99.5%		46
97.5%		37
90.0%		26
75.0%	quartile	22
50.0%	median	18
25.0%	quartile	15
10.0%		14
2.5%		11
0.5%		11
0.0%	minimum	11

Table B19. Moments for “plastic limit” field.

Moments	
Number Records	1985
Number Missing	2607
Mean	19
Variance	38
Standard Deviation	6
Coeff. of Variation	32
Skewness	1.60
Kurtosis	3.62

Plasticity index (percent)

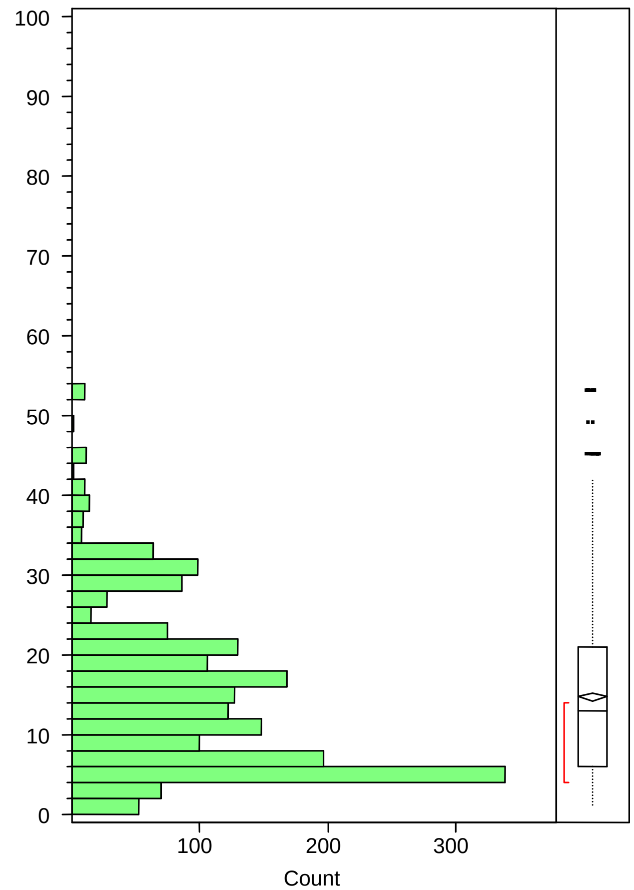

Figure B17. Distribution of records by “plasticity index’ field.

Table B20. Quantiles for “plasticity index” field.

Quantiles		
100.0%	maximum	53
99.5%		53
97.5%		37
90.0%		30
75.0%	quartile	21
50.0%	median	13
25.0%	quartile	6
10.0%		4
2.5%		1
0.5%		1
0.0%	minimum	1

Table B21. Moments for “plasticity index” field.

Moments	
Number Records	1998
Number Missing	2594
Mean	15
Variance	103
Standard Deviation	10
Coeff. of Variation	69
Skewness	0.89
Kurtosis	0.44

Optimum moisture content, CE 55 (weight percent)

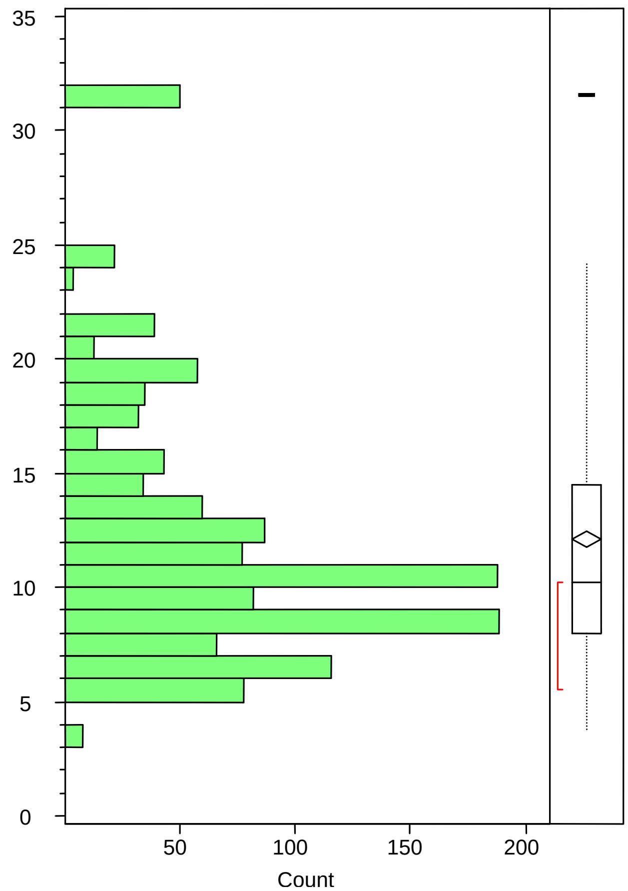

Figure B18. Distribution of records by “optimum moisture content” field.

Table B22. Quantiles for “optimum moisture content” field.

Quantiles		
100.0%	maximum	31.5
99.5%		31.5
97.5%		31.5
90.0%		19.6
75.0%	quartile	14.5
50.0%	median	10.2
25.0%	quartile	8.0
10.0%		6.0
2.5%		5.5
0.5%		3.8
0.0%	minimum	3.8

Table B23. Moments for “optimum moisture content” field.

Moments	
Number Records	1295
Number Missing	3297
Mean	12
Variance	0.4
Standard Deviation	6
Coeff. of Variation	49
Skewness	1.49
Kurtosis	2.20

Maximum dry density, CE 55 (pounds per cubic foot)

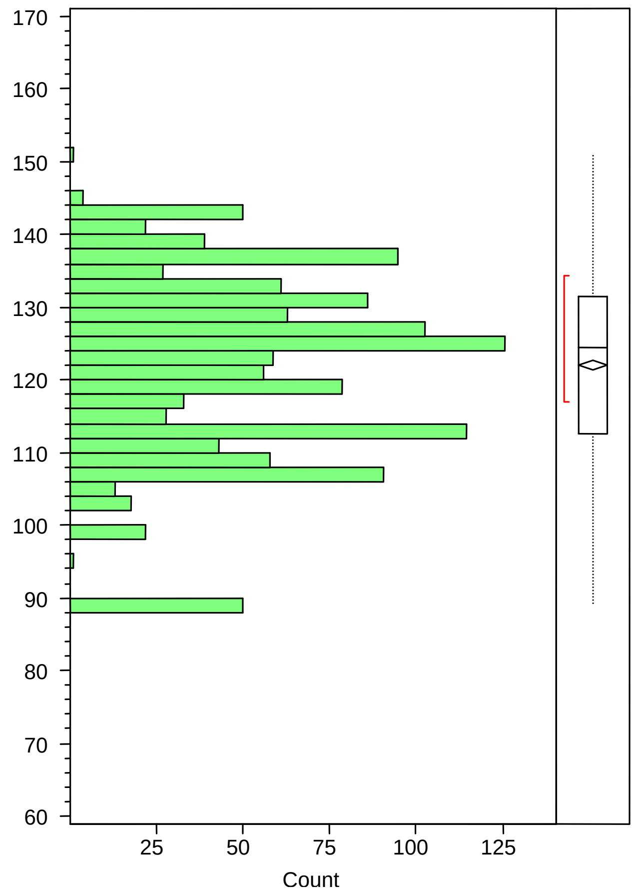

Figure B19. Distribution of records by "maximum dry density" field.

Table B24. Quantiles for "maximum dry density" field.

Quantiles		
100.0%	maximum	151.0
99.5%		143.5
97.5%		143.5
90.0%		137.6
75.0%	quartile	131.5
50.0%	median	124.5
25.0%	quartile	112.5
10.0%		107.0
2.5%		89.0
0.5%		89.0
0.0%	minimum	89.0

Table B25. Moments for "maximum dry density" field.

Moments	
Number Records	1343
Number Missing	3249
Mean	122.1
Variance	161.8
Standard Deviation	12.7
Coeff. of Variation	10
Skewness	–0.48
Kurtosis	–0.06

Moisture content, gravimetric (weight percent)

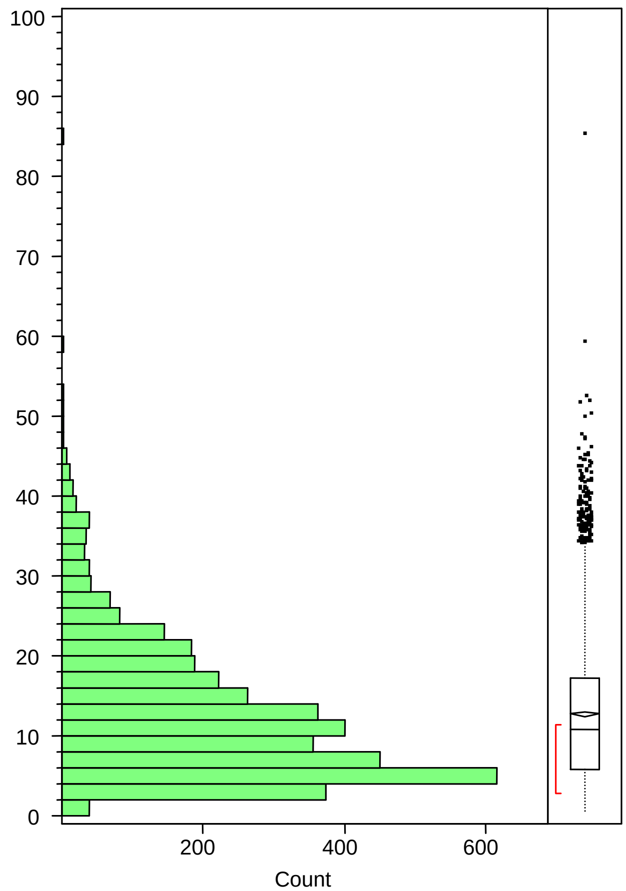

Figure B20. Distribution of records by “gravimetric moisture content” field.

Table B26. Quantiles for “gravimetric moisture content” field.

Quantiles		
100.0%	maximum	85.3
99.5%		44.1
97.5%		36.3
90.0%		24.2
75.0%	quartile	17.1
50.0%	median	10.8
25.0%	quartile	5.8
10.0%		3.9
2.5%		2.5
0.5%		1.6
0.0%	minimum	0.5

Table B27. Moments for “gravimetric moisture content” field.

Moments	
Number Records	4020
Number Missing	572
Mean	13
Variance	0.8
Standard Deviation	9
Coeff. of Variation	69
Skewness	1.39
Kurtosis	2.75

Field CBR (percent)

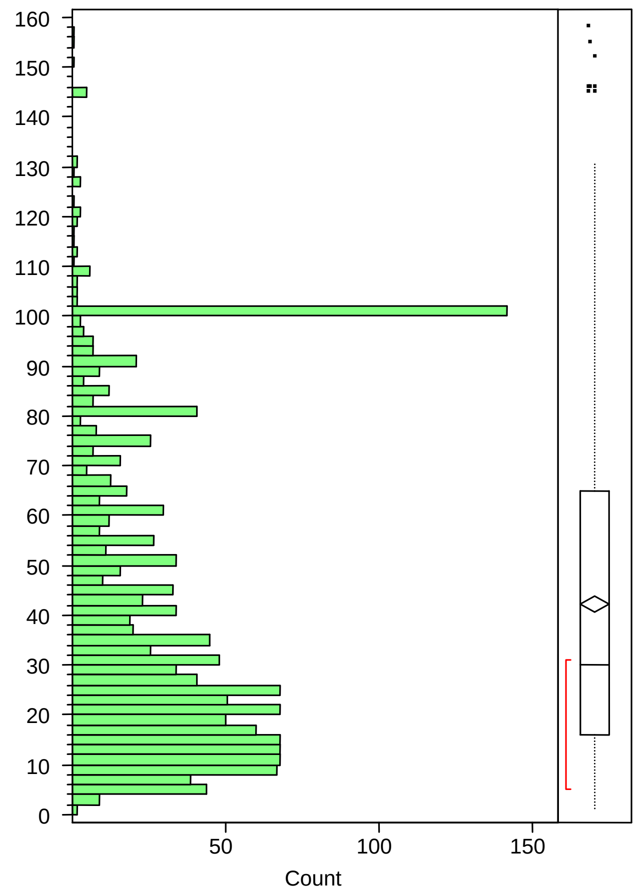

Figure B21. Distribution of records by "field CBR" field.

Table B28. Quantiles for "field CBR" field.

Quantiles		
100.0%	maximum	158
99.5%		145
97.5%		101
90.0%		100
75.0%	quartile	65
50.0%	median	30
25.0%	quartile	16
10.0%		9
2.5%		5
0.5%		3
0.0%	minimum	1

Table B29. Moments for "field CBR" field.

Moments	
Number Records	1533
Number Missing	3059
Mean	42
Variance	1055
Standard Deviation	32
Coeff. of Variation	77
Skewness	0.86
Kurtosis	–0.30

Field dry density (pounds per cubic foot)

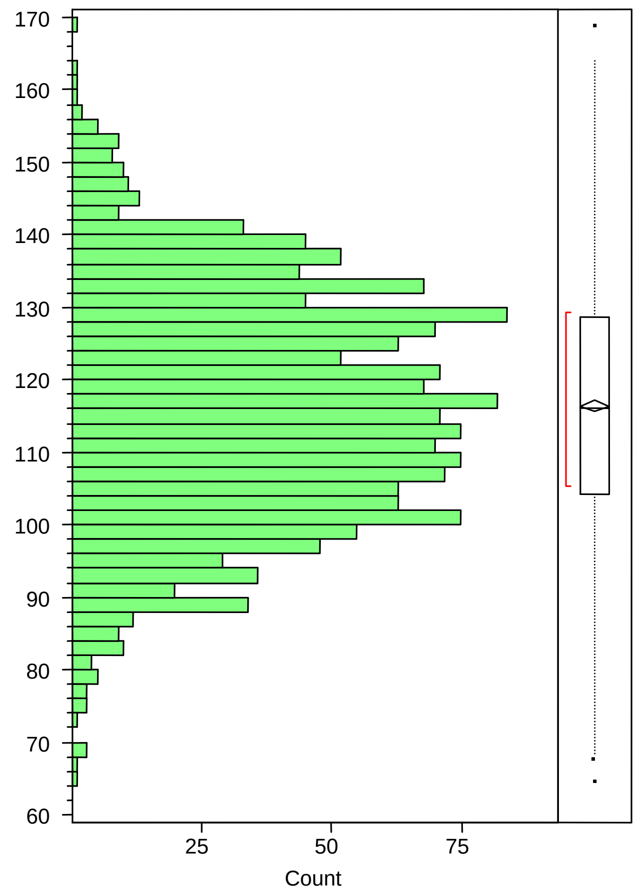

Figure B22. Distribution of records by “field dry density” field.

Table B30. Quantiles for “field dry density” field.

Quantiles		
100.0%	maximum	168.7
99.5%		155.1
97.5%		147.7
90.0%		137.3
75.0%	quartile	128.7
50.0%	median	116.2
25.0%	quartile	104.3
10.0%		96.0
2.5%		86.6
0.5%		74.7
0.0%	minimum	64.5

Table B31. Moments for “field dry density” field.

Moments	
Number Records	1686
Number Missing	2906
Mean	116.4
Variance	262.1
Standard Deviation	16.2
Coeff. of Variation	14
Skewness	–0.01
Kurtosis	–0.33

¾ inch sieve, average percent passing

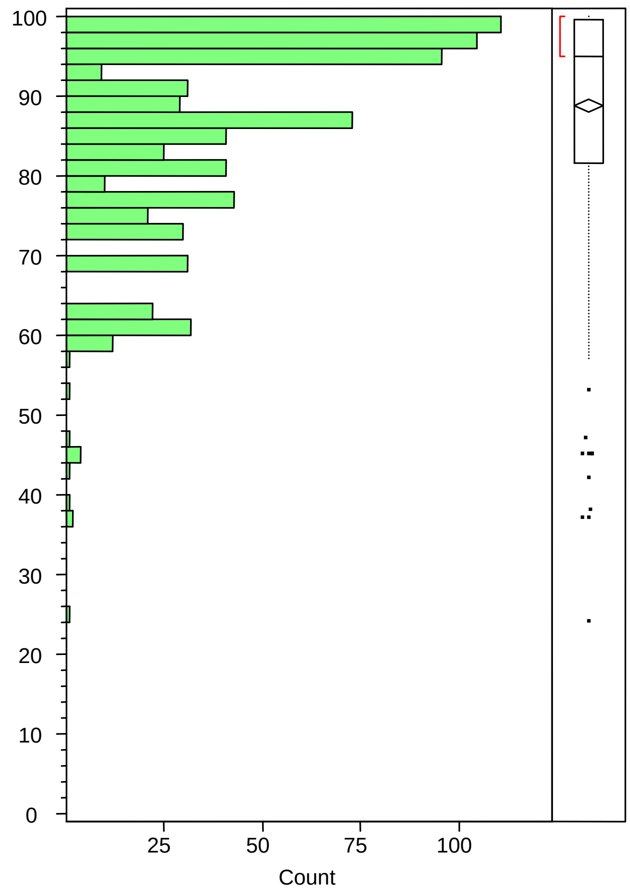

Figure B23. Distribution of records by "¾ inch sieve, average percent passing."

Table B32. Quantiles for "¾ inch sieve, average percent passing."

Quantiles		
100.0%	maximum	100.0
99.5%		100.0
97.5%		100.0
90.0%		100.0
75.0%	quartile	99.5
50.0%	median	95.0
25.0%	quartile	81.5
10.0%		69.5
2.5%		60.0
0.5%		42.1
0.0%	minimum	24.0

Table B33. Moments for "¾ inch sieve, average percent passing."

Moments	
Number Records	1004
Number Missing	3588
Mean	89
Variance	1.6
Standard Deviation	13
Coeff. of Variation	14
Skewness	–1.30
Kurtosis	1.42

⅜ inch sieve, average percent passing

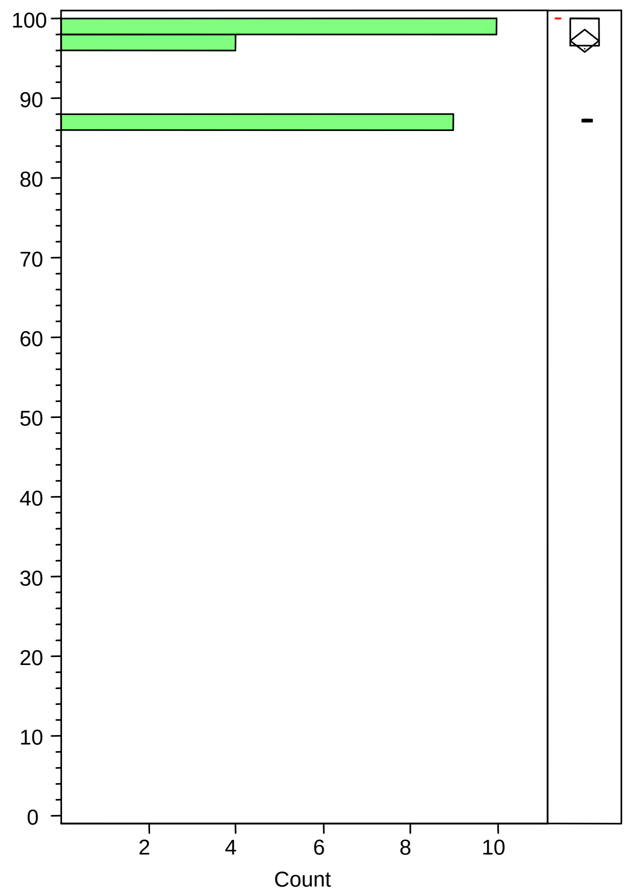

Figure B24. Distribution of records by "⅜ inch sieve, average percent passing."

Table B34. Quantiles for "⅜ inch sieve, average percent passing."

Quantiles		
100.0%	maximum	100.0
99.5%		100.0
97.5%		100.0
90.0%		100.0
75.0%	quartile	100.0
50.0%	median	100.0
25.0%	quartile	96.5
10.0%		87.0
2.5%		87.0
0.5%		87.0
0.0%	minimum	87.0

Table B35. Moments for "⅜ inch sieve, average percent passing."

Moments	
Number Records	49
Number Missing	4543
Mean	97
Variance	0.3
Standard Deviation	5
Coeff. of Variation	5
Skewness	–1.55
Kurtosis	0.58

#4 sieve, average percent passing

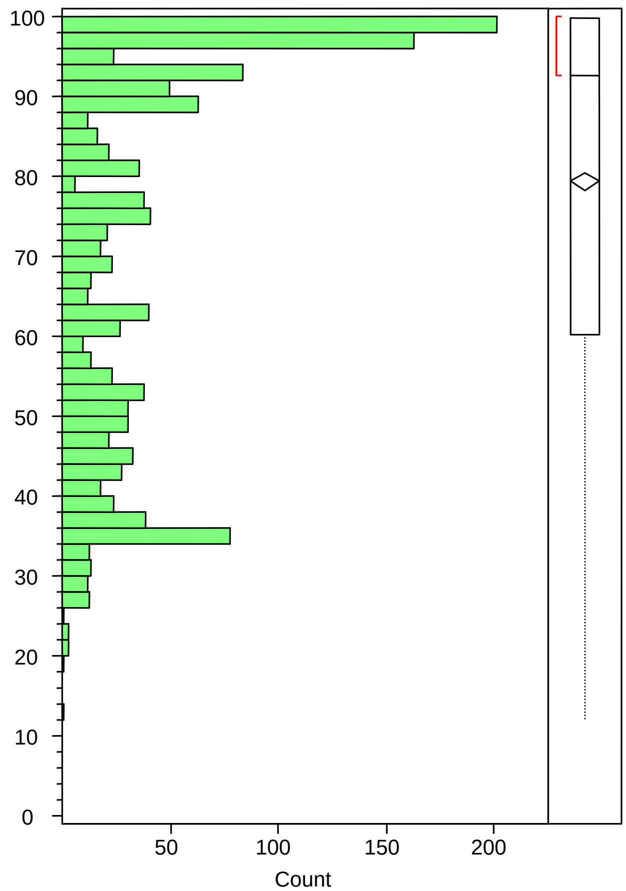

Figure B25. Distribution of records by "#4 sieve, average percent passing."

Table B36. Quantiles for "#4 sieve, average percent passing."

Quantiles		
100.0%	maximum	100.0
99.5%		100.0
97.5%		100.0
90.0%		100.0
75.0%	quartile	99.8
50.0%	median	92.5
25.0%	quartile	60.3
10.0%		38.0
2.5%		31.0
0.5%		24.3
0.0%	minimum	12.0

Table B37. Moments for "#4 sieve, average percent passing."

Moments	
Number Records	1817
Number Missing	2775
Mean	79
Variance	5.7
Standard Deviation	24
Coeff. of Variation	30
Skewness	–0.83
Kurtosis	–0.82

#10 sieve, average percent passing

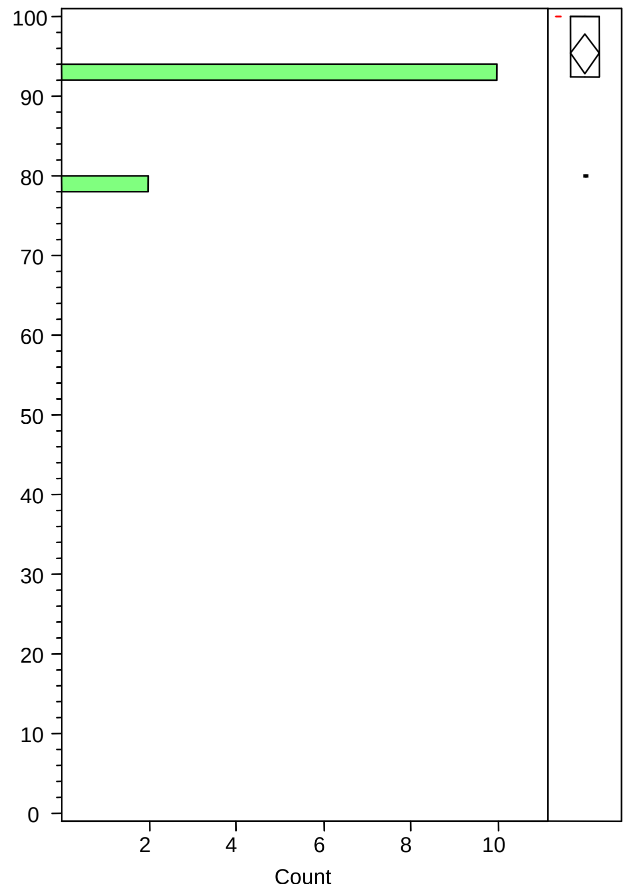

Figure B26. Distribution of records by “#10 sieve, average percent passing.”

Table B38. Quantiles for “#10 sieve, average percent passing.”

Quantiles		
100.0%	maximum	100.0
99.5%		100.0
97.5%		100.0
90.0%		100.0
75.0%	quartile	100.0
50.0%	median	100.0
25.0%	quartile	92.4
10.0%		87.4
2.5%		79.8
0.5%		79.8
0.0%	minimum	79.8

Table B39. Moments for “#10 sieve, average percent passing.”

Moments	
Number Records	25
Number Missing	4567
Mean	95
Variance	0.4
Standard Deviation	6
Coeff. of Variation	6
Skewness	–1.38
Kurtosis	1.84

#40 sieve, average percent passing

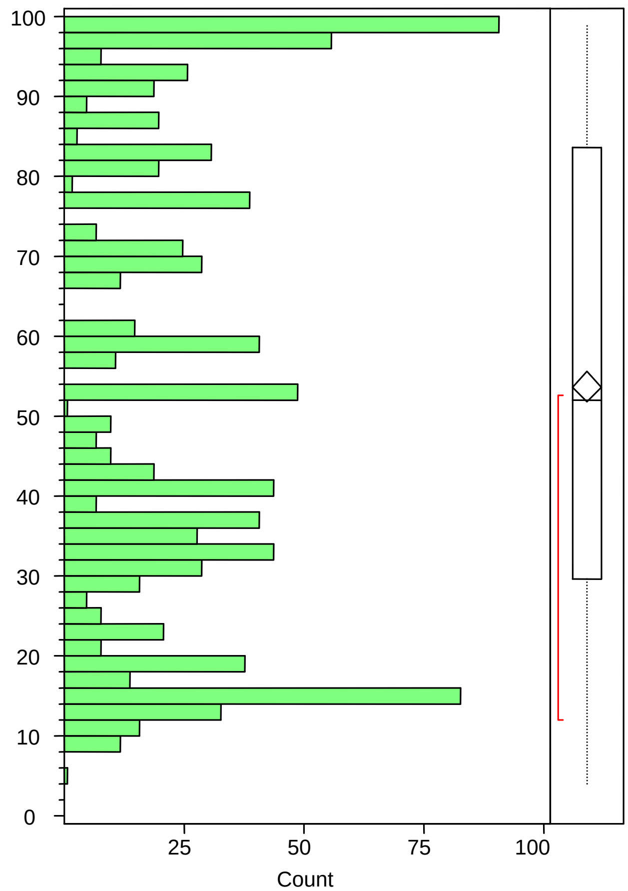

Figure B27. Distribution of records by "#40 sieve, average percent passing."

Table B40. Quantiles for "#40 sieve, average percent passing."

Quantiles		
100.0%	maximum	99.0
99.5%		99.0
97.5%		99.0
90.0%		97.5
75.0%	quartile	83.5
50.0%	median	52.0
25.0%	quartile	29.5
10.0%		15.0
2.5%		11.0
0.5%		8.5
0.0%	minimum	4.0

Table B41. Moments for "#40 sieve, average percent passing."

Moments	
Number Records	1004
Number Missing	3588
Mean	54
Variance	9.0
Standard Deviation	30
Coeff. of Variation	56
Skewness	0.15
Kurtosis	–1.38

#100 sieve, average percent passing

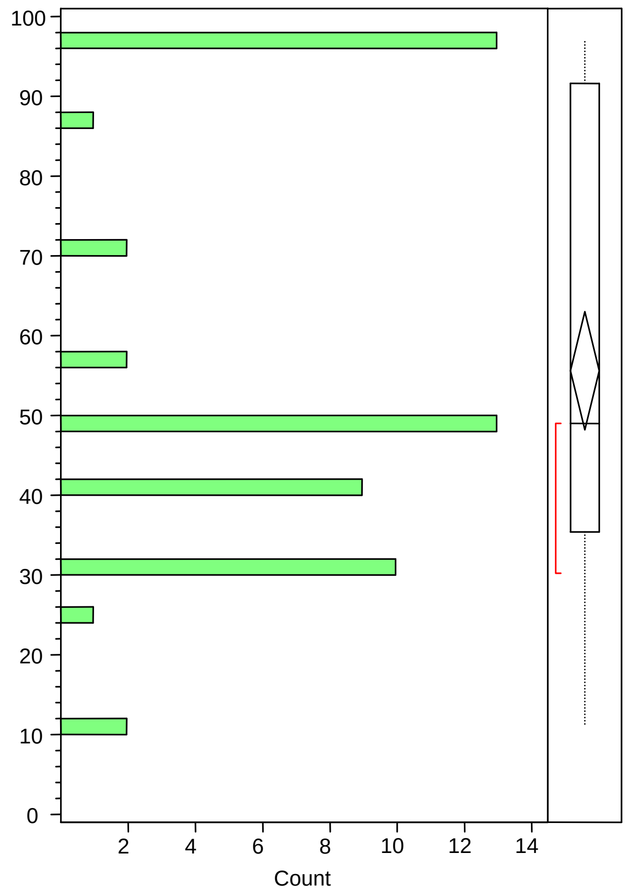

Figure B28. Distribution of records by "#100 sieve, average percent passing."

Table B42. Quantiles for "#100 sieve, average percent passing."

Quantiles		
100.0%	maximum	96.9
99.5%		96.9
97.5%		96.9
90.0%		96.9
75.0%	quartile	91.6
50.0%	median	49.0
25.0%	quartile	35.3
10.0%		30.1
2.5%		10.9
0.5%		10.9
0.0%	minimum	10.9

Table B43. Moments for "#100 sieve, average percent passing."

Moments	
Number Records	53
Number Missing	4539
Mean	56
Variance	7.2
Standard Deviation	27
Coeff. of Variation	48
Skewness	0.55
Kurtosis	–1.03

#200 sieve, average percent passing

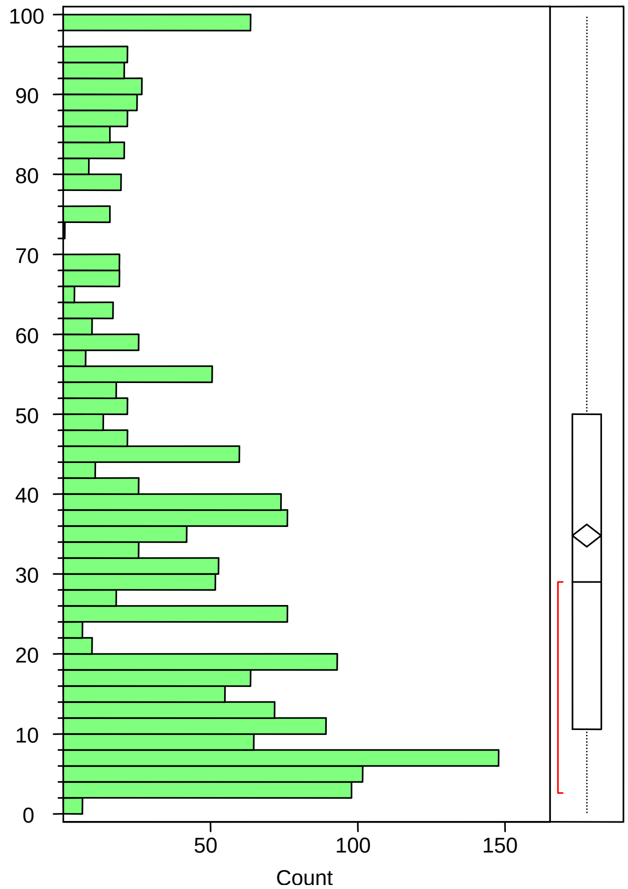

Figure B29. Distribution of records by "#200 sieve, average percent passing."

Table B44. Quantiles for "#200 sieve, average percent passing."

Quantiles		
100.0%	maximum	100.0
99.5%		100.0
97.5%		98.0
90.0%		87.5
75.0%	quartile	50.0
50.0%	median	29.0
25.0%	quartile	10.5
10.0%		5.0
2.5%		3.0
0.5%		2.0
0.0%	minimum	0.0

Table B45. Moments for "#200 sieve, average percent passing."

Moments	
Number Records	1834
Number Missing	2758
Mean	35
Variance	8.3
Standard Deviation	29
Coeff. of Variation	83
Skewness	0.86
Kurtosis	–0.38

0.005 mm, average percent passing

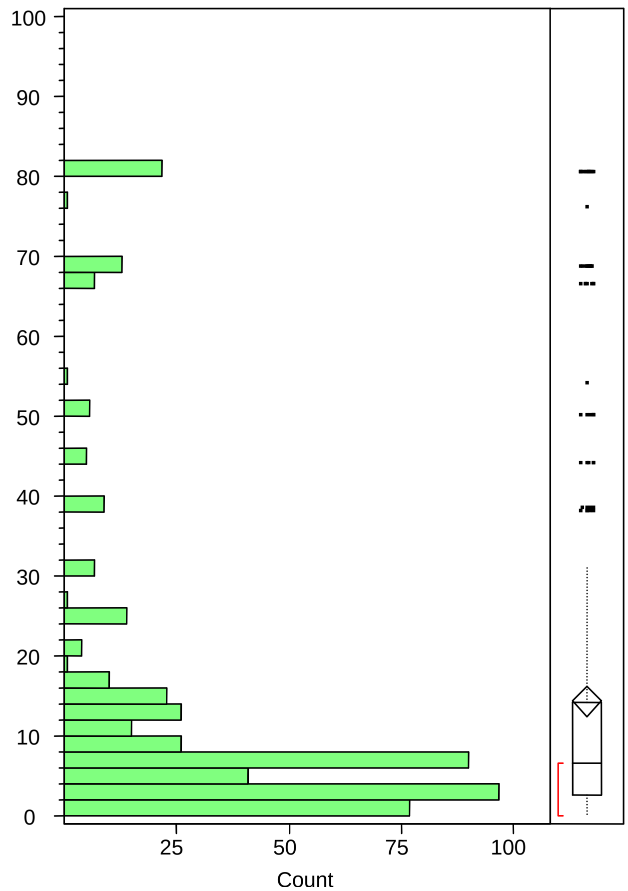

Figure B30. Distribution of records by "0.005 mm, average percent passing."

Table B46. Quantiles for "0.005 mm, average percent passing."

Quantiles		
100.0%	maximum	80.5
99.5%		80.5
97.5%		80.5
90.0%		50.0
75.0%	quartile	14.1
50.0%	median	6.5
25.0%	quartile	2.5
10.0%		0.0
2.5%		0.0
0.5%		0.0
0.0%	minimum	0.0

Table B47. Moments for "0.005 mm, average percent passing."

Moments	
Number Records	496
Number Missing	4096
Mean	14
Variance	4.4
Standard Deviation	21
Coeff. of Variation	147
Skewness	2.16
Kurtosis	3.55

0.001 mm, average percent passing

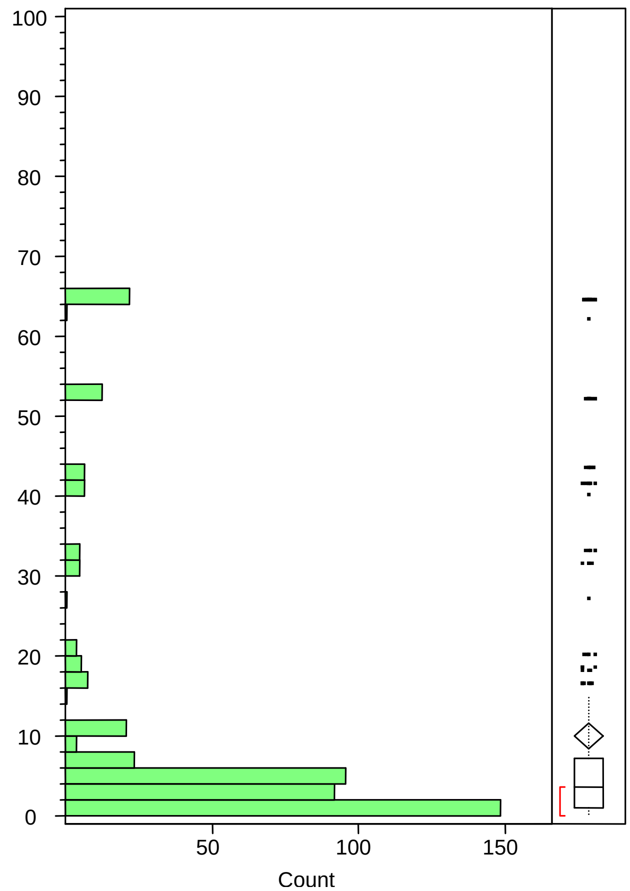

Figure B31. Distribution of records by "0.001 mm, average percent passing."

Table B48. Quantiles for "0.001 mm, average percent passing."

Quantiles		
100.0%	maximum	64.5
99.5%		64.5
97.5%		64.5
90.0%		41.5
75.0%	quartile	7.1
50.0%	median	3.5
25.0%	quartile	1.0
10.0%		0.0
2.5%		0.0
0.5%		0.0
0.0%	minimum	0.0

Table B49. Moments for "0.001 mm, average percent passing."

Moments	
Number Records	466
Number Missing	4126
Mean	10
Variance	2.9
Standard Deviation	17
Coeff. of Variation	170
Skewness	2.27
Kurtosis	3.93

Appendix C: Comparison of Database Record Distribution to Reported Values in the Literature for Selected Fields in the Full Database

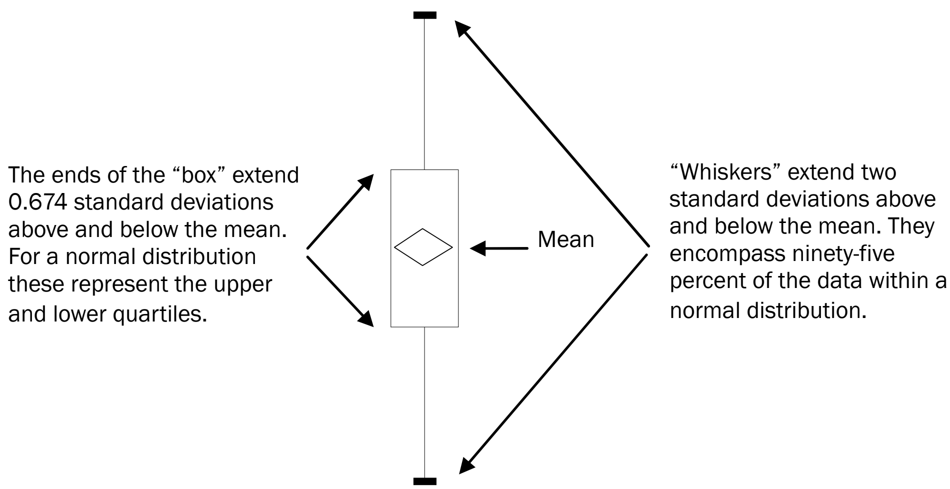

Figure C1. Key to box and whisker plot elements.

Table C1. Key to literature sources of box and whisker plot data.

Key	Reference
a	Auff and Choummanivong (1994)
b	Auff and Laksmanto (1994)
c	Auff and Yeo (1992)
d	Fredlund and Dahlman (1972)
e	Hampton et al. (1962)
f	Ingles (1972)
g	Kelley (1969)
h	Kennedy et al. (1975)
i	Krahn and Fredlund (1983)
j	Mitchell et al. (1977)
k	Schultze (1972)
l	Sherman (1971)
m	State of California (1967)
n	Wahls and Futrell (1966)
o	Willenbrock (1974)
p	Yeo and Auff (1995)
q	Yoder and Witczak (1975)

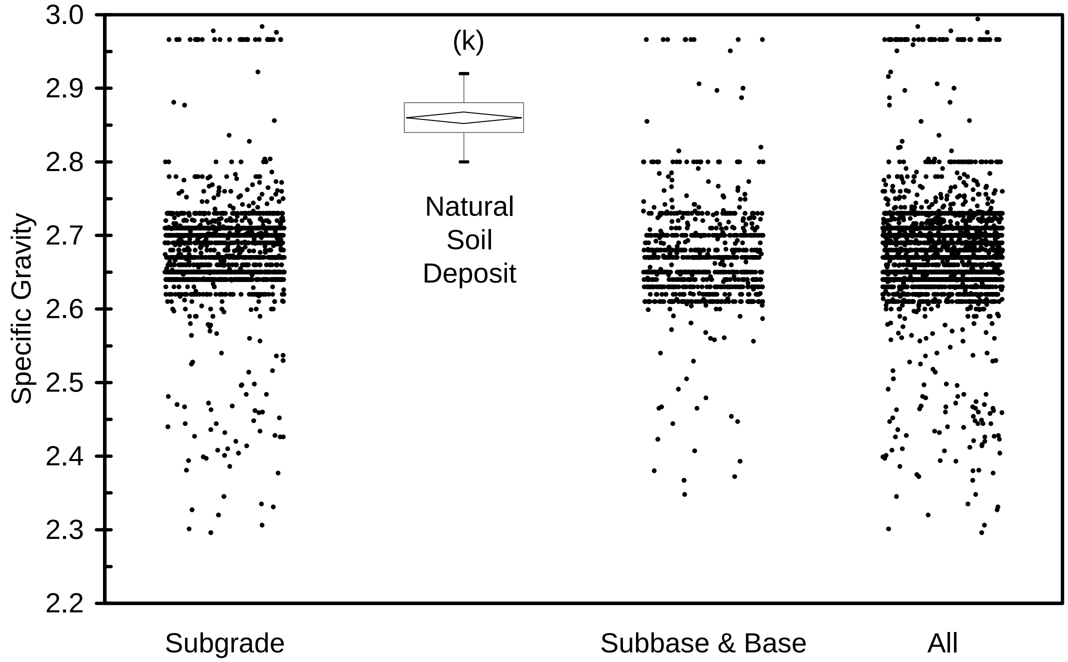

Figure C2. Comparison of database records and literature reports of specific gravity.

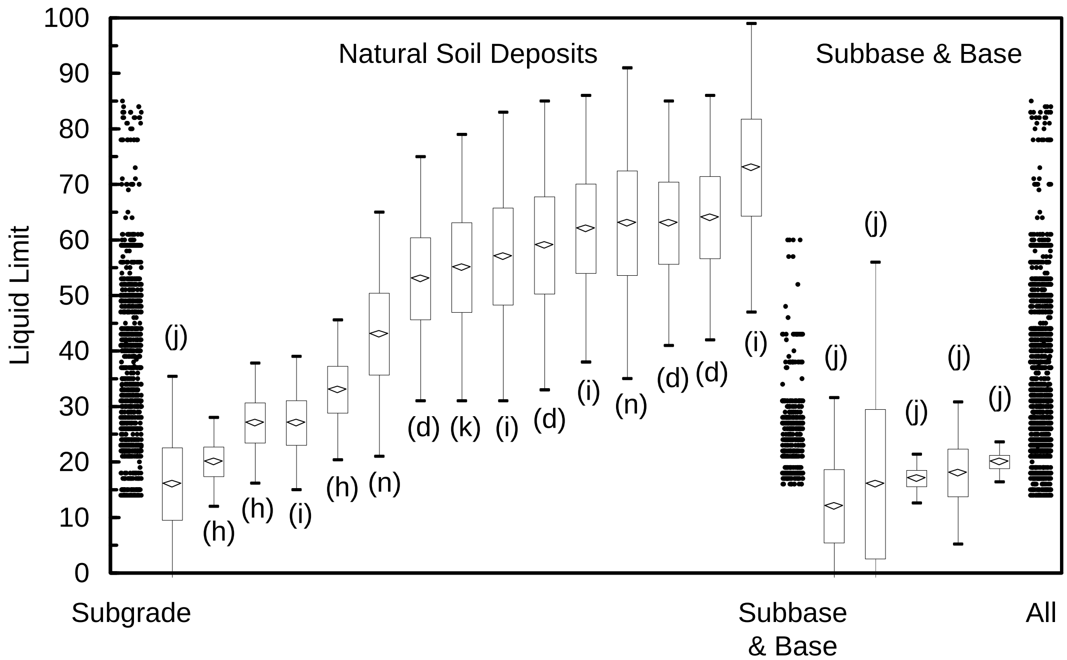

Figure C3. Comparison of database records and literature reports of liquid limit.

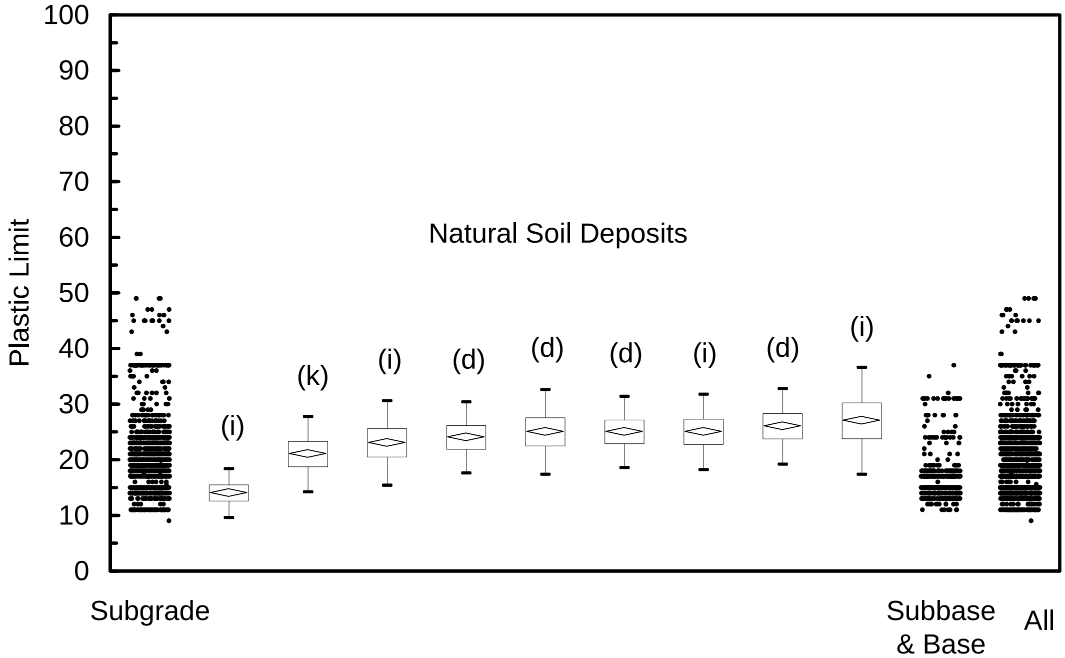

Figure C4. Comparison of database records and literature reports of plastic limit.

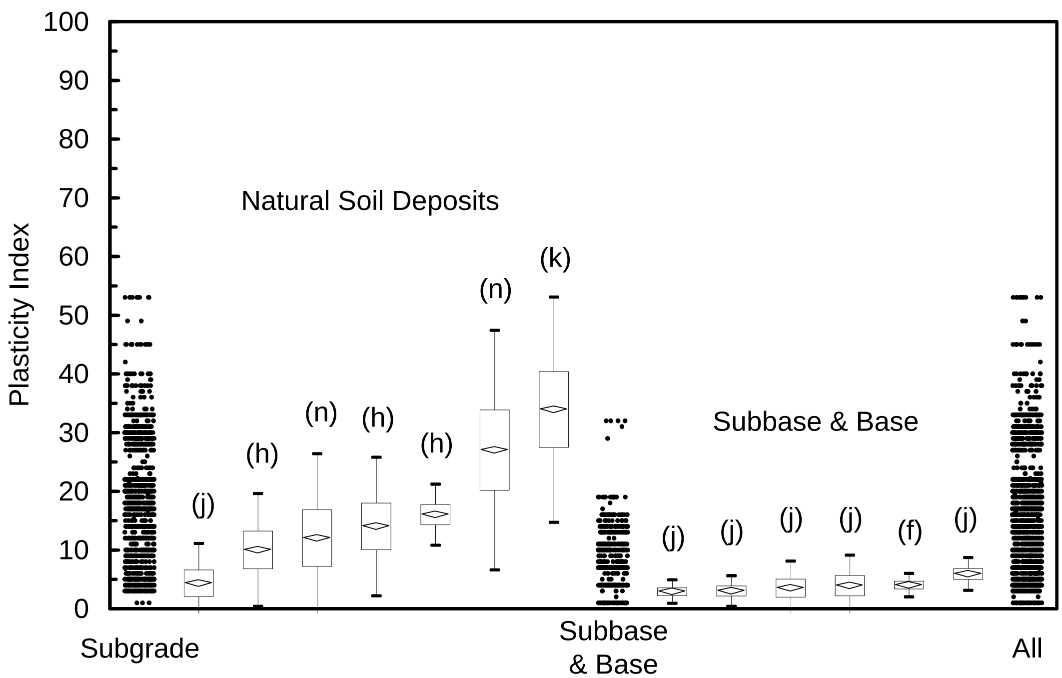

Figure C5. Comparison of database records and literature reports of plasticity index.

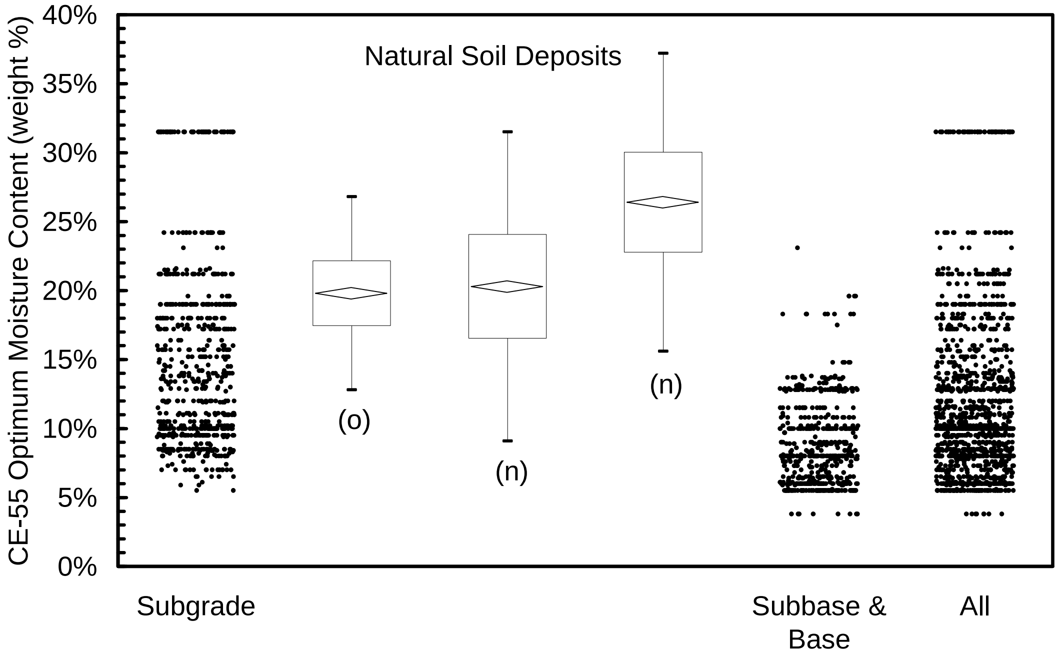

Figure C6. Comparison of database records and literature reports of CE 55 optimum moisture content.

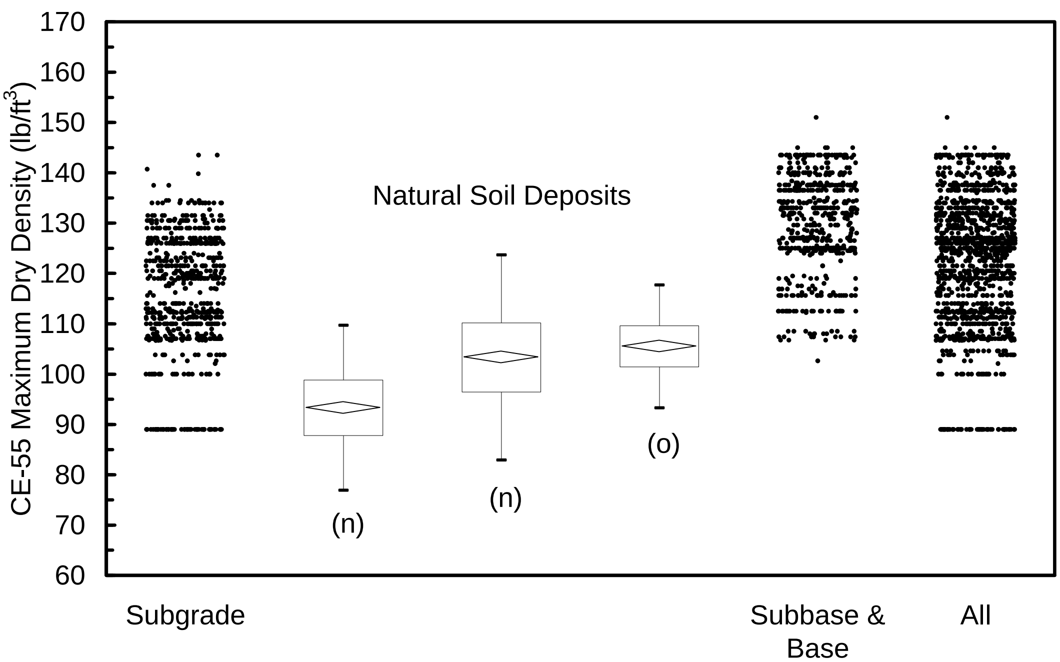

Figure C7. Comparison of database records and literature reports of CE 55 maximum dry density.

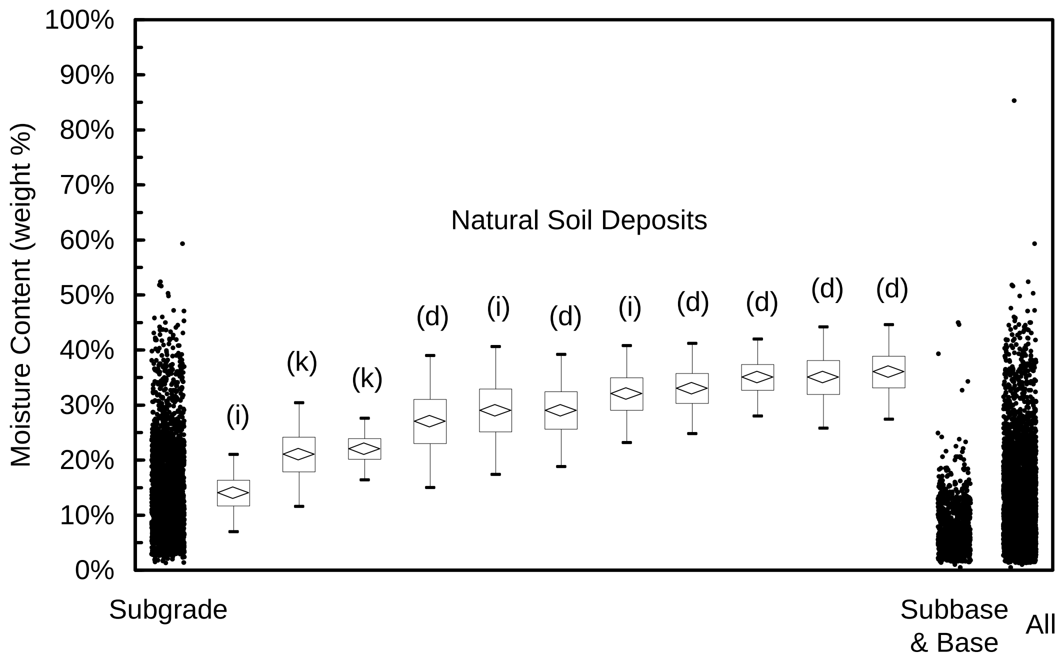

Figure C8. Comparison of database records and literature reports of gravimetric moisture content.

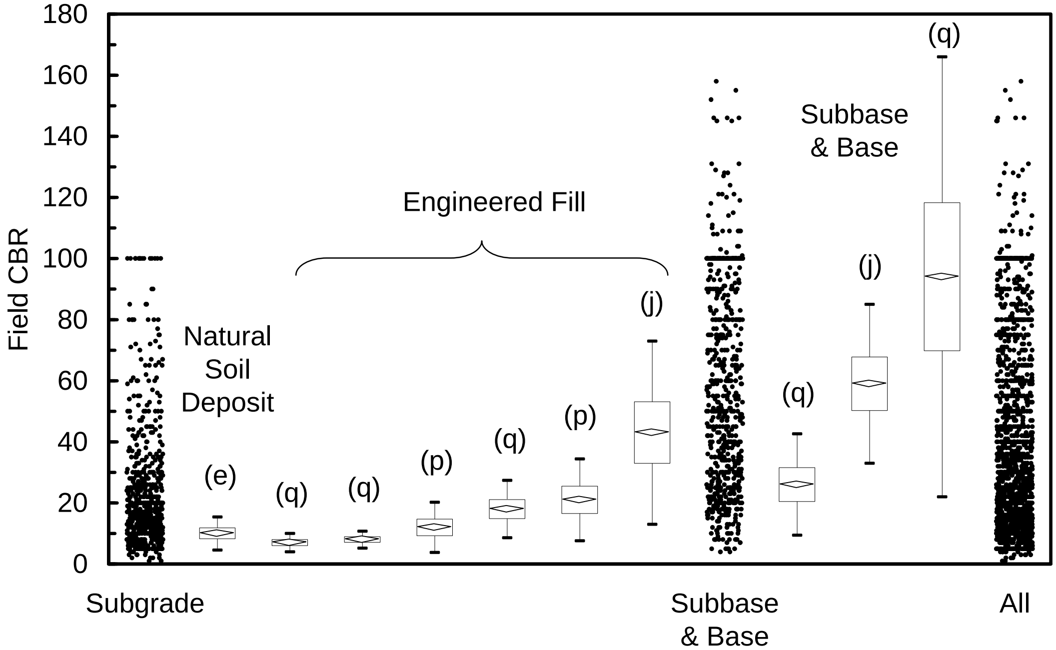

Figure C9. Comparison of database records and literature reports of field California bearing ratio.

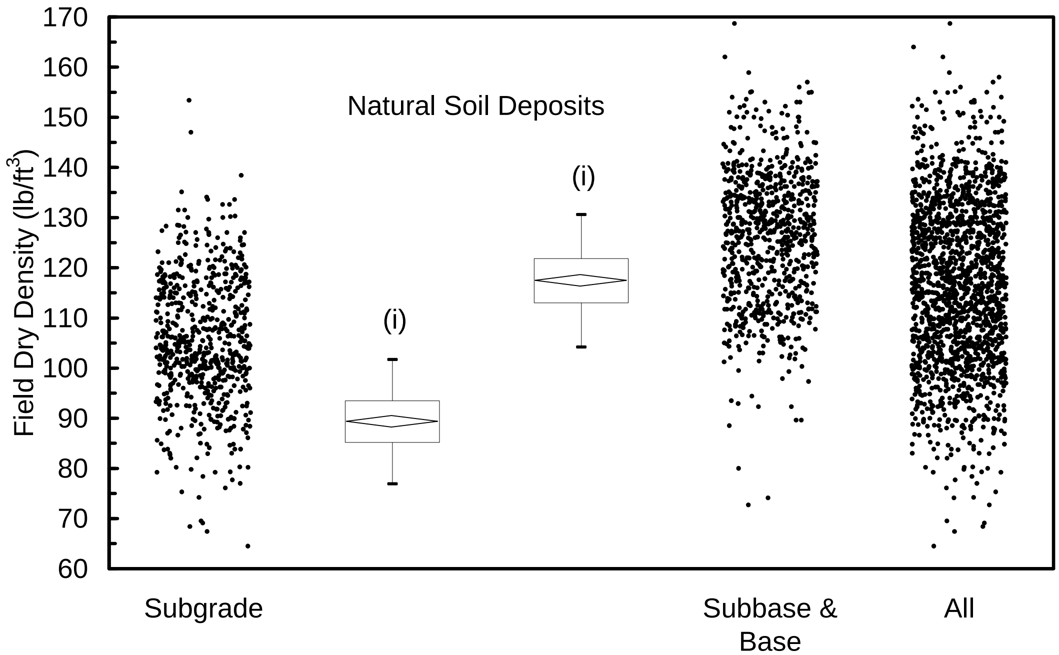

Figure C10. Comparison of database records and literature reports of field dry density.

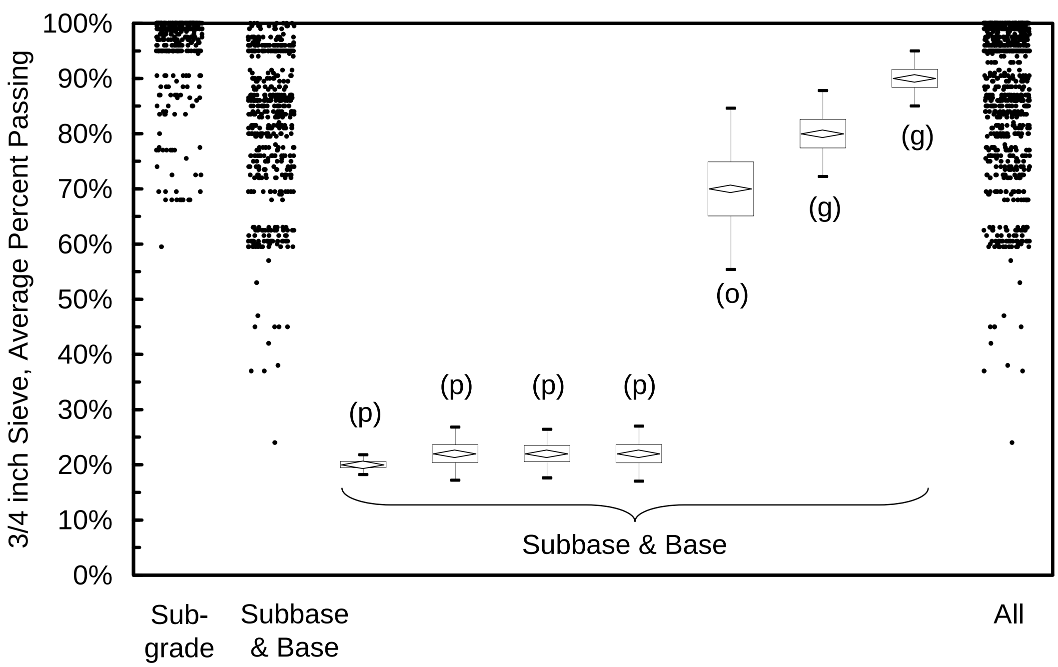

Figure C11. Comparison of database records and literature reports of average percent passing the ¾ inch sieve.

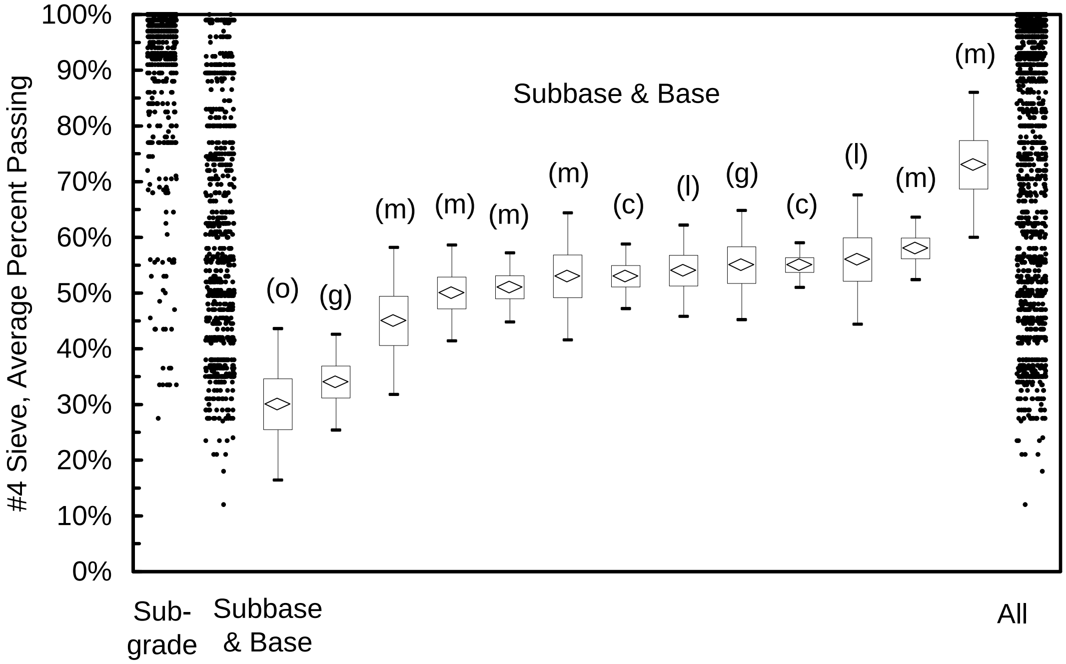

Figure C12. Comparison of database records and literature reports of average percent passing the #4 sieve.

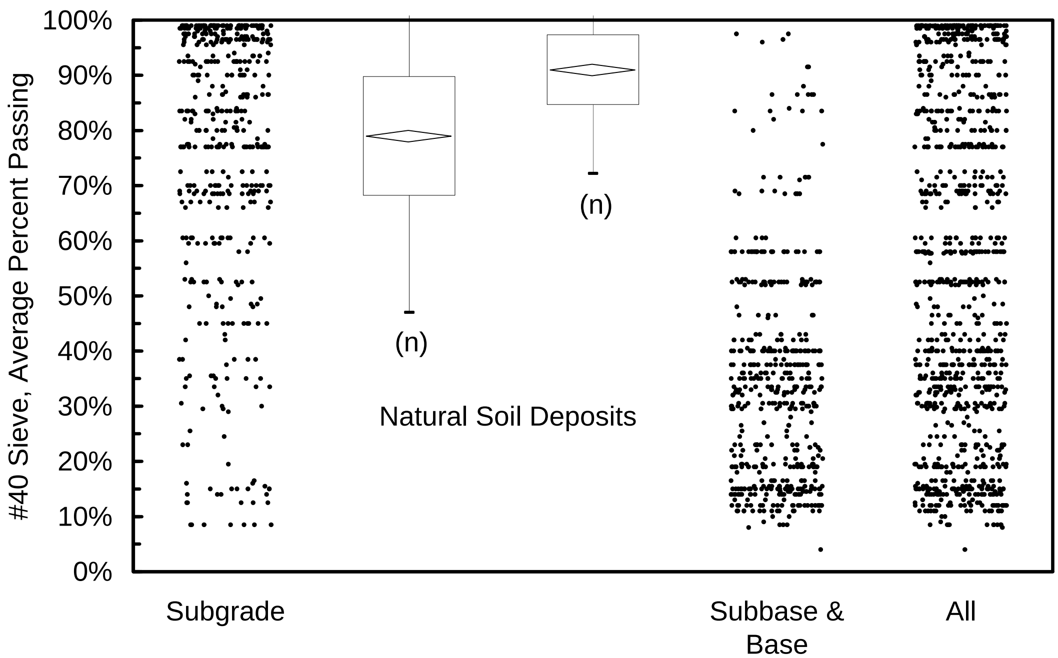

Figure C13. Comparison of database records and literature reports of average percent passing the #40 sieve.

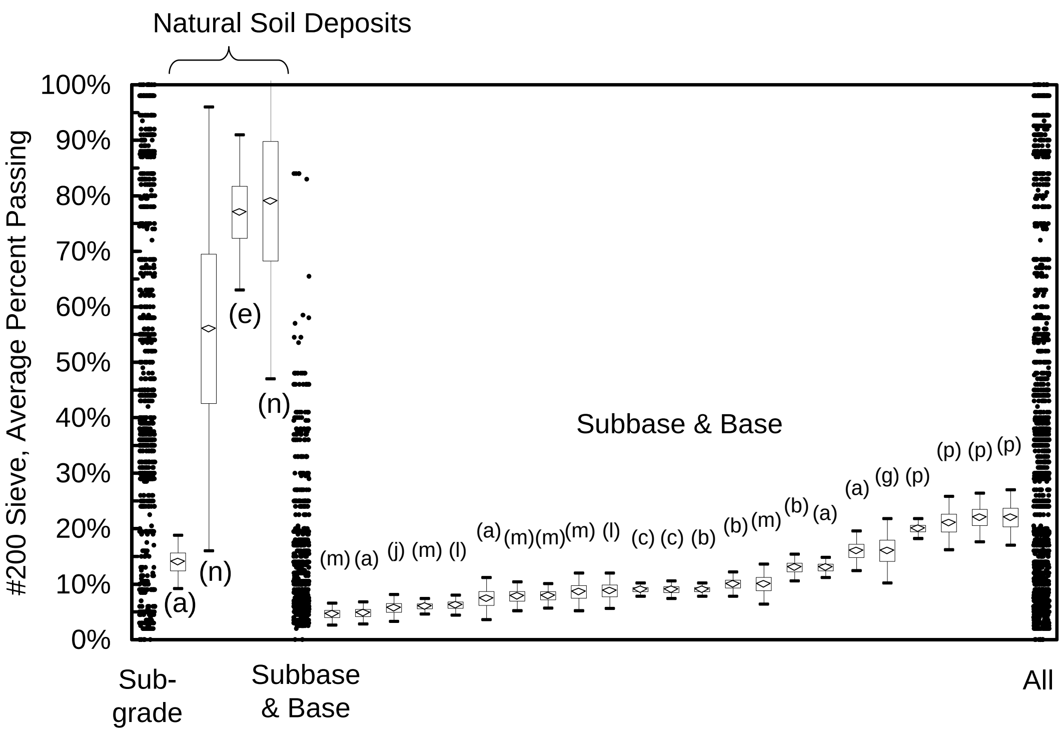

Figure C14. Comparison of database records and literature reports of average percent passing the #200 sieve.

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14. ABSTRACT

A global database of in situ soil test measurements and associated attributes was compiled for use in developing California bearing ratio (CBR) prediction models. From a variety of potential data sources, a collection of U.S. Army and Air Force airfield pavement research and evaluation reports was selected for inclusion. The schema includes data fields for common geotechnical parameters related to airfield pavement strength and geomorphological features associated with soil formation. More than 4,500 records from 46 test sites, representing 10 countries and 4 continents, were gathered and more than 1,500 of these contain field CBR test values. The database includes a wide variety of Unified Soil Classification System (USCS) soil types from a diversity of natural environments. The distribution of the numeric parameters in the database fall within the range of published distributions for natural soils reported in the literature.

15. SUBJECT TERMS

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